THE TECHNOLOGY AND COSTS OF CONTROL AUTOMOTIVE EMISSIONS IN CANADA

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FOR

Environmental Protection Service
Environment Canada

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SUMMARY AND CONCLUSIONS

The study described in this report was undertaken as part of the Socio-Economic Impact Analysis (SEIA) of the proposed hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxides (NOx) emission standards of 0.25 HC, 4.35 CO, and 0.62 NOx grams per kilometre (0.41 HC, 7.0 CO, and 1.0 NOx grams per mile). The announcement of the proposed standards and that a SEIA would be prepared was made in the CANADA GAZETTE, Part I on September 18, 1982.

The main purposes of the study were to examine the technology required for more stringent control of automobile emissions and to determine the additional costs of the hardware that would be required to meet the more stringent emission standards. The basis for the analyses was existing data. No experimental work, laboratory testing, or other new work was carried out for this study.

In addition to emission control technology and costs, the effects on emissions of: cold weather conditions such as those encountered in Canada and fuel composition were considered.

The main findings and conclusions are as follows:

Emission Control Technology to Meet Current Standards

A non-catalyst emission control system has sufficient emission control margin to allow most manufacturers to meet current Canadian emission control standards. However, if time, and human resources are limited and good fuel consumption is an important goal, the oxidation catalyst is a more cost-effective option for many manufacturers. The choice of a three-way catalyst system, or more correctly, a U.S. federal emission control system, is dictated solely by production volume considerations, and this system would be selected whenever costs for development, certification, and compliance of a unique Canadian system exceed the costs of a U.S. federal system.

Toyota and Honda were the only motor vehicle manufacturers that provided data on the costs of current emission control systems. The retail price equivalent (i.e. the cost at the consumer level) of a non-catalyst system was estimated to be $182 by Toyota and $150 to $475 by Honda. The retail price equivalent of an oxidation catalyst system was estimated to be $227 by Toyota and $410 to $610 by Honda. The authors' estimates of retail price equivalents, based on U.S. Environmental Protection Agency (EPA) data, are $130 and $390 for a non-catalyst and oxidation catalyst systems respectively. All of the retail price equivalents above are in 1983 Canadian dollars.

Emission Control Technology to Meet Proposed Standards

There is clear agreement that the basic emission control approach will be the closed loop, three-way catalyst system. In addition to the catalyst, the typical system will consist of exhaust gas recirculation (EGR), air injection (pulse air in light vehicles, air pump in the heavy vehicles), oxygen sensor, micro-computer, and feed-back carburetor or electronic fuel injection. More manufacturers will adopt single point electronic injection in place of carburetors because of slightly lower cost and more precise fuel control. Engine modifications, incorporating new fast burn concepts, will be more common. The lightest vehicles could likely will meet the proposed standards with oxidation catalyst svstems. Open loop three-way systems would also be used in some light, four cylinder vehicles.

While some manufacturers have indicated that they will need to use three-way plus oxidation catalyst systems, it is the technical judgement of the authors that the add-on oxidation catalyst is not required with a 4.35 CO grams per kilometre (7.0 CO in grams per mile) standard. The manufacturers also made this judgement during testimony before a U.S. Congressional Committee meeting in 1982 when they argued for a relaxed CO standard (reference 4).

The table below is a comparison of the manufacturer and EPA estimates of incremental increases in price to upgrade emission control systems from present systems to those needed to meet proposed standards.

COMPARISON OF INCREMENTAL RETAIL PRICES TO MEET PROPOSED STANDARDS

(1983 Canadian Dollars)

Action/Source	Incremental Price Increase
From Non-Catalyst to Feedback 3-Way Catalyst	
EPA (carburetor)	$ 360
(single point injection)	510
Honda	480 - 805
Toyota (carburetor)	418
Renault	940
From Oxidation to Feedback 3-way Catalyst	
EPA (carburetor)	100
(single point injection)	250
Chrysler (carburetor)	210
Honda	345 - 545
Toyota (carburetor)	373
Volkswagen	greater than 155
From Oxidation to Feedback 3-way + Ox Catalyst	
EPA (carburetor)	240
Ford (carburetor)	175
Toyota (carburetor)	452

As expected, there is a range in reported prices which reflects differences in production volume, hardware sophistication, cost accounting, allocation practices, and other cost factors. The authors' best estimate of the incremental cost impact to the consumer of adopting the proposed standards is about $200 for upgrading the current oxidation catalyst system to a three-way and about $400 for upgrading the current non-catalyst system to a three-way system.

Fuel Consumption Impacts

The answer to the question "What is the fuel consumption impact of the proposed emissions standards?" is difficult and speculative. However, all factors considered, it is the judgement of the authors that the fuel consumption impact of adopting the proposed standards will be minimal and slightly positive --- a fuel consumption improvement of 1 to 2 percent. This is based on the author's judgement that expanded use and improvement of electronics, fuel metering systems, and fast burn techniques will bring about a 5-6% improvement in U.S. federal systems by MY 1986 which will offset any fuel consumption increases due to the richer air/fuel calibrations of the three-way systems.

Durability, Maintenance, Driveability and Other Impacts

The manufacturers responding to the survey questionnaire uniformly reported that they do not expect any impacts on durability, maintenance, or driveability as a result of the proposed standards.

We agree with the manufacturers' comments. In fact, the proposed standards will require increased use of unleaded fuels and stainless steel components so that exhaust system durability will be enhanced. Since these systems will be calibrated richer and employ advanced electronic controls, driveability should also be enhanced -- including cold weather starting and performance.

Lead-time Considerations

The manufacturers were uniform in reporting on their lead-time requirements. If a U.S. emission control system is available and will not require much change, then 12 to 18 months is adequate lead-time. If the system requires additional redesign and certification testing then 36 months lead-time is more appropriate.

We conclude that a 30 month lead-time schedule would be appropriate because it allows manufacturers to recalibrate U.S. federal systems and take advantage of the more lenient CO standard compared to U.S. standards. This allows trade-offs for lower cost (e.g. elimination of add-on oxidation catalysts) and better fuel consumption (by taking advantage of electronic improvements).

Evaporative Emissions Standards

The scope of work for the study also required examination of the feasibility of adopting a 2 gram SHED evaporative standard. None of the manufacturers responding to the survey questionnaire reported any concern or difficulty in achieving a 2 gram SHED evaporative standard. This is not surprising since most manufacturers use the U.S evaporative control design which already meets this standard. In a few instances, some models may have to be upgraded. For example, Toyota reported that most of their light duty vehicles already comply, but their 1.5 and 1.6 litre engine families would require modifications costing $ 23 additional.

Diesel-Engined Passenger Cars

The technical feasibility for diesel-engined passenger cars meeting the proposed standards depends on whether a particulate standard is established for this class of vehicle,the engine size/vehicle weight combination, and the lead-time available.

Without particulate standards, all diesel engines with the exception of the large displacement engines (greater than 3 litres) in vehicles over 1360 kg (3000 lb), not incorporating divided chambers, are capable of meeting the proposed NOx standard of 0.62 g/km. The lighter vehicles could use mechanically-controlled EGR systems while the heaviest vehicles would have to use electronically-controlled EGR systems. Lead-times of 3 to 5 years would be required, depending upon whether electronic EGR systems would have to be employed (longer time for electronic EGR development).

If a particulate standard of 0.37 g/km were adopted along with the proposed NOx standard, most diesel engines could still comply but longer lead-times would be necessary to develop the electronic EGR systems and particulate control techniques. It may be necessary for the largest engines to incorporate add-on particulate traps. A 5 year lead-time would be necessary.

If a particulate standard of 0.12 g/km (0.2 g/mile) were adopted along with the proposed NOx standard, it is likely that all diesel engines, with the exception of the small displacement 4 cylinder engines, would require some form of add-on particulate trap. A minimum lead-time of 5-7 years would be required.

The above comments apply only to the question of technical feasibility. Whether or not the manufacturers would develop models to meet the proposed standards is another question. Most manufacturers have commented that the Canadian automotive market is small and does not justify large expenditures of time and resources for unique Canadian calibrations. Therefore, if the proposed standards were adopted, the availability of diesel-engined models would depend to a large measure on market considerations and the levels of U.S and California standards. For example, GM recently announced that the large diesel-engined models would not be available in California because the size of the market did not justify development of the required emission controls. At the present time, the market for diesel-powered vehicles is very small in Canada (less than 5% of sales).

Light-Duty Trucks

Of the proposed changes considered in this study, adoption of 1.05 HC, 11.16, 1.43 NOx g/km (1.7 HC, 18 CO, 2.3 NOx gram/mile) for light-duty trucks would have the least impact. Most manufacturers already use the same or recalibrated version of the U.S. federal truck emission control systems for gasoline-engined LDTs and would use these systems to comply.

Retail price increases will be of the order of $ 50 to recalibrate -- mainly increasing catalyst volume. No impacts on fuel consumption, maintenance, driveability, or durability are expected.

Manufacturers offering diesel engines would not have to make any changes as the diesel engine currently offered is capable of meeting the new standards as well.

Any standard more stringent than that above would have significant impacts on technology and cost -- especially, if they were as stringent as proposed for passenger cars. This is because these standards would be more stringent than any proposed by the U.S. EPA and manufacturers would have to adopt systems similar to those used in California.

Alternate Emission Control Standards; Gasoline-Fueled Passenger Cars

As the standards are tightened, manufacturers will shift from non-catalyst designs to oxidation catalyst or U.S. federal three-way systems. At around 0.93 HC, 9.3 CO, 1.24 NOx g/km (1.5 HC, 15 CO, 2.0 NOx g/mi) all cars, with the exception of the very smallest (mini-compacts), will have shifted to the catalyst systems. The primary reason for this breakpoint is cost rather than limitations on technology. Electronic or continuous mechanical multi-point fuel injection systems, electronic computerized control systems, and thermal reactors are available technologies that would permit lower emissions. However, the high costs of these systems combined with development and certification costs, would make catalytic systems a more cost effective approach for a small market like Canada.

The breakpoint for the use of three-way catalysts appears to be around 0.93 NOx g/km (1.5 g/mi). Again, technologies are available to give lower emissions, especially for compacts and sub-compacts, but, for cost reasons, most manufacturers would opt to use U.S. federal three-way systems.

Alternate Emission Standards; Diesel-Fueled Passenger Cars

The 0.93 NOx g/km (1.5 g/mi) level is also a significant breakpoint for diesel-engined passenger cars. More stringent levels may eliminate the large, eight cylinder diesels and would require most manufacturers to develop electronic EGR systems in lieu of mechanically-controlled EGR systems. Since the diesel markets are small in North America, some manufacturers might drop diesel models all together. This NOx level also represents a breakpoint where some manufacturers might need to utilize particulate traps if particulate standards are superimposed on the NOx standards.

Alternate Emissions Standards; Light-duty Trucks

The standards 1.05 HC, 11.16 CO, 1.43 NOx g/km (1.7 HC, 18 CO, 2.3 NOx g/mile) were originally selected by the U.S. EPA as levels that would not force the use of catalysts on light-duty trucks. However, many manufacturers have opted to use catalysts anyway. Since the oxidation catalyst systems are capable of much lower emissions, LDT standards could be reduced to around 0.5 HC, 6.2 CO, 1.43 NOx g/km (0.8 HC, 10 CO, 2.3 NOx g/mile) without forcing significant changes in technology usage.

The ramifications of standards lower than those in the U.S. are clear.

Unless the U.S. federal standards are also reduced, model availability in Canada would be reduced and many manufacturers would use California emission control systems.

Cold Weather Effects on Emissions

A number of strategies for controlling cold weather emissions have been identified, but none of them offers an optimal solution, or, perhaps even enough advantage to consider changing current practices. The alternative strategies are:

- require cold temperature testing;
- modify the test procedure;
- issue design standards;
- optional cold weather testing; and
- emission control system device certification.

Effect of Fuel Composition Changes on Emissions

The consensus of EPA and the automotive industry is that MMT produces significant adverse effects on HC emissions. It is the judgement of the authors that it would be very difficult for manufacturers to certify vehicles at the proposed levels unless the HC standard were relaxed to compensate for the predicted HC increases. However, the authors are especially concerned with the potential for premature failures of oxygen sensors if MMT fuels are used. Admittedly the CRC study of effects on sensors involved only a few first generation sensors, but the results suggested accelerated failure of sensors. The CRC results were based on seven 1977-78 model year cars, all of which were calibrated to meet California standards. Advances in sensor technology since then may have alleviated some of the problem. If the sensor prematurely fails on a three-way catalyst system, feed-back control is lost. Unless the micro-computer control system is pre-programmed to adjust the air/fuel ratio under sensor failure conditions, excessive CO emissions will result. On the other hand, if the system is pre-programmed to operate at lean air/fuel ratios then NOx control is sacrificed.

The only other major fuel composition concern expressed by the industry involved diesel fuels. Mercedes-Benz, in particular, provided extensive comment and a technical report (reference 9) on diesel fuel quality and it's impact on emissions. Mercedes-Benz would like to see regulation or tight specification of diesel fuel quality.

Mercedes-Benz's concern stems from the fact that growing demand for middle distillates by non-transportation users (e.g. the chemical industry) may outstrip the fractional distillation yield of diesel fuel and other middle distillates from crude oil. This may require refiners to increase the heavier components of diesel fuel and to produce diesel fuels by cracking (thermal, catalytic, etc.) or reforming other crude oil components. EPA contractor studies (reference 10) have suggested that initial use of synthetic crudes derived from tar sands and coal might be used as direct blends (with hydro-treating) with diesel fuels.

RÉSUMÉ À L'INTENTION DE LA DIRECTION: TECHNIQUES ET COÛTS D'ABAISSEMENT DES ÉMISSIONS PAR LES AUTOMOBILES AU CANADA*

préparé par
Piicrusso Research Associates Inc. et DeKany Associates

L'étude décrite dans le présent rapport a été entreprise dans le cadre de l'Analyse des incidences socio-économiques de normes proposées limitant les émissions d'hydrocarbures (HC), de monoxyde de carbone (CO) et d'oxydes d'azote (NO_x) à 0,25, 4,35 et 0,62 grammes au kilomètre respectivement. Ces projets de normes et la tenue d'une analyse des incidences socio-économiques ont été annoncés dans la Gazette du Canada, Partie I, le 18 septembre 1982.

Les principaux objectifs de l'étude étaient d'examiner les techniques requises pour abaisser davantage les émissions causées par les automobiles et de déterminer les coûts additionnels liés au matériel requis pour respecter ces normes. Les analyses ont porté sur les données existantes et n'ont comporté aucune recherche expérimentale, aucun essai en laboratoire ou autre travail supplémentaire. Les données ont été tirées en partie d'un sondage effectué auprès des fabricants de véhicules automobiles.

Outre les techniques et coûts d'abaissement des émissions, les effets du temps froid comme on en connaît au Canada et de la composition de l'essence sur les émissions ont été examinés.

Les principales observations et conclusions sont les suivantes:

Techniques de dépollution permettant de satisfaire aux normes actuelles

Un système dépolluant non-catalytique donne à la plupart des fabricants une marge de manoeuvre suffisante pour leur permettre de satisfaire aux normes canadiennes actuelles relatives aux émissions. Toutefois, si le temps et les ressources humaines sont limités et si la consommation d'essence est un objectif important, le catalyseur d'oxydation constitue après une analyse coût-efficacité, un choix plus avantageux pour beaucoup de fabricants. Le choix d'un dispositif catalytique trifonctionnel, ou plus précisément, d'un dispositif dépolluant conforme aux normes fédérales américaines, est dicté uniquement par des considérations de volume de production; un tel dispositif serait choisi si les coûts nécessaires pour mettre au point un dispositif spécial pour le Canada, pour le faire homologuer et assurer sa conformité aux normes dépassaient les coûts d'un dispositif américain.

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* MAS, contrat n° KE145-2-0739, octobre 1983

Toyota et Honda ont été les seuls fabricants d'automobiles à fournir des données sur les coûts des dispositifs dépolluants actuels. Toyota a estimé à 182 $, et Honda, entre 150 et 475 $ le prix de détail équivalent d'un dispositif non-catalytique (c.-à-d. le coût pour le consommateur). Dans le cas d'un dispositif catalytique d'oxydation, les deux compagnies l'ont estimé respectivement à 227 $ et entre 410 et 610 $. En se fondant sur des données de l'U.S. Environmental Protection Agency (EPA), les auteurs estiment pour leur part ces prix à 130 et 190 $ pour les dispositifs non-catalytiques et les dispositifs catalytiques d'oxydation respectivement. Tous ces prix sont en dollars canadiens de 1983.

Moyens d'abaissement des émissions pour satisfaire aux normes proposées

Il apparaît évident qu'en général les fabricants opteront pour le système catalytique trifonctionnel à boucle fermée. Outre le catalyseur, le système typique comportera le recyclage des gaz d'échappement, l'injection d'air (air pulsé dans les véhicules légers et pompe à air dans les véhicules lourds), un détecteur d'oxygène, un micro-ordinateur et un carburateur à courant de retour ou un système d'injection électronique. Plus de fabricants adopteront l'injection électronique en un seul point au lieu des carburateurs en raison des coûts un peu plus faibles et d'une régulation plus précise. Les modifications des moteurs de façon à appliquer les nouveaux concepts de combustion rapide seront plus fréquentes. Les véhicules plus légers devraient pouvoir satisfaire aux normes proposées à l'aide des dispositifs catalytiques d'oxydation. Des dispositifs trifonctionnels à boucle ouverte seraient également utilisés dans certains véhicules légers à quatre cyclindres.

Même si certains fabricants ont indiqué qu'ils devront utiliser des dispositifs catalytiques combinés (trifonctionnels et d'oxydation), selon les auteurs, le catalyseur auxiliaire d'oxydation n'est pas nécessaire pour atteindre la norme de 4,35 grammes de CO au kilomètre. Les fabricants ont également exprimé cette opinion lorsqu'ils ont témoigné devant un comité du Congrès américain en 1982 en vue d'obtenir un assouplissement de la norme pour le CO.

Le tableau présenté plus loin permet de comparer les estimations des fabricants et de l'EPA quant aux augmentations de prix qu'entraînera le perfectionnement des dispositifs dépolluants pour satisfaire aux normes proposées.

Comme on peut s'y attendre, l'écart entre les prix reflète des différences touchant le volume de production, le perfectionnement du matériel, la comptabilisation des coûts, les pratiques de ventilation et d'autres facteurs influant sur les coûts. Selon le meilleur jugement des auteurs, l'effet de l'adoption des normes proposées pour le consommateur devrait être d'environ 200 $ si on passe du dispositif catalytique d'oxydation actuel à un dispositif trifonctionnel et d'environ 400 $ si on passe d'un dispositif non catalytique à un dispositif trifonctionnel.

Répercussions sur la consommation d'essence

Répondre à la question "Quel effet auront les normes proposées d'émission sur la consommation d'essence?" est difficile et relève de la spéculation. Après considération de tous les facteurs, les auteurs estiment que l'effet sera minime et légèrement positif, soit une amélioration de 1 à 2 p. 100 de la consommation d'essence. Ils sont arrivés à cette conclusion en estimant que l'utilisation accrue et le perfectionnement de l'électronique, des systèmes de contrôle de l'alimentation en carburant et des techniques de combustion rapide entraîneront une amélioration d'environ 5 ou 6 p. 100 avec les dispositifs américains pour les modèles de 1986, ce qui compensera les augmentations de la consommation d'essence dues aux mélanges air-essence enrichis qu'exigent les dispositifs trifonctionnels.

COMPARAISON DES AUGMENTATIONS DE PRIX AU DÉTAIL QU'ENTRAÎNERONT LES NORMES PROPOSÉES (dollars canadiens de 1983)

Action/source	Augmentation du prix
Passer d'un système non catalytique à un système catalytique trifonctionne à boucle fermée	
EPA (carburateur)	360 $
(injection en un seul point)	510
Honda	480 - 805
Toyota (carburateur)	418
Renault	940

Passer d'un système catalytique d'oxydation à un système catalytique trifonctionnel à boucle fermée

EPA (carburateur)	100 $
(injection en un seul point)	250
Chrysler (carburateur)	210
Honda	345 - 545
Toyota (carburateur)	373
Volkswagen	plus de 155

Passer d'un système catalytique d'oxydation à un système catalytique combiné (trifonctionnel + oxydation) à boucle fermée

EPA (carburateur)	240 $
Ford (carburateur)	175
Toyota (carburateur)	452

Effets sur la durabilité, l'entretien, la conduisabilité et d'autres caractéristiques

Dans leurs réponses au sondage, les fabricants ont tous indiqué qu'ils ne prévoyaient pas de répercussions sur la durabilité, l'entretien et la conduisabilité.

Les auteurs sont du même avis. De fait, les normes proposées entraîneront une utilisation accrue des essences sans plomb et des composantes en acier inoxydable, ce qui accroîtra la durabilité des systèmes d'échappement. Comme ces systèmes seront réglés pour la combustion d'un mélange plus riche et emploieront des dispositifs électroniques plus perfectionnés, la conduisabilité devrait également être améliorée, y compris le démarrage et la performance par temps froid.

Délais

Les fabricants s'accordent au sujet des délais nécessaires. Selon eux, si un système américain est disponible et n'exige pas beaucoup de modifications, un délai de 12 à 18 mois est suffisant. Si le système doit être modifié et soumis à des essais d'homologation, un délai de 36 mois est alors considéré comme plus acceptable.

Un calendrier prévoyant un délai de 30 mois serait donc approprié, car cela permettrait aux fabricants de rajuster des systèmes américains et de tirer profit de la limite plus faible qu'aux État-Unis pour le CO. Des compromis techniques seront possibles pour abaisser le coût (p. ex. élimination des catalyseurs auxiliaires d'oxydation) et améliorer la consommation d'essence (grâce aux améliorations des composantes électroniques).

Normes pour les pertes par évaporation

Les auteurs ont également fait une étude de faisabilité de l'application d'une norme limitant à 2 grammes les pertes par évaporation. Aucun des fabricants ayant répondu au sondage n'a indiqué des préoccupations ou des difficultés à ce sujet. Cela n'est pas étonnant, car la plupart d'entre eux utilisent le système américain d'abaissement des pertes par évaporation qui satisfait déjà à la norme. Il est possible que certains modèles doivent être améliorés. Par exemple, Toyota a indiqué que la plupart de ses véhicules légers respectent déjà cette limite, mais les familles des moteurs de 1,5 et 1,6 litre devront subir des modifications qui entraîneront un coût additionnel de 23 $ par véhicule.

Automobiles à moteur diesel

Pour ces voitures, la faisabilité technique de satisfaire aux normes proposées dépend de leur assujettissement ou non à une norme pour les particules, du rapport de la masse du véhicule et de la puissance du moteur ainsi que du délai accordé.

Sans norme pour les particules, tous les moteurs diesel, à l'exception des grosses cylindrées (plus de 3 litres) dans des véhicules pesant plus de 1360 kg non munis de chambres divisées, réussiront à respecter la limite proposée de 0,62 g/km pour les NO_x. Pour y arriver, les véhicules plus légers devront être équipés de systèmes de recirculation des gaz d'échappement à commande mécanique, tandis que les plus lourds devront posséder des systèmes à commande électronique. Des délais de trois à cinq ans seront nécessaires suivant qu'il faille ou non recourir à des systèmes électroniques qui exigeront plus de temps pour leur mise au point.

Si une norme limitant les émissions de particules à 0,37 g/km était adoptée en même temps que la norme proposée pour les NO_x, la plupart des moteurs diesel pourraient encore les respecter, mais des délais plus longs seraient nécessaires pour mettre au point les systèmes de recirculation des gaz d'échappement à commande électronique et les techniques d'abaissement des émissions de particules. Il faudra peut-être utiliser des pièges auxiliaires à particules avec les plus gros moteurs. Un délai de cinq ans serait nécessaire.

Si les émissions de particules étaient limitées à 0,12 g/km, il est probable que tous les moteurs diesel, à l'exception des petites cylindrées quatre cylindres, auraient besoin d'un dispositif auxiliaire quelconque pour le piégeage des particules. Un délai minimal de cinq à sept ans serait alors nécessaire.

Les remarques précédentes concernent seulement la faisabilité; reste à savoir si les fabricants décideront de construire des modèles répondant aux normes proposées. La plupart ont fait remarquer que le marché canadien de l'automobile est petit et ne justifie pas qu'on consacre du temps et des ressources considérables à des ajustements spéciaux. Par conséquent, si les normes proposées étaient adoptées, la disponibilité de modèles à moteur diesel dépendrait dans une forte mesure de considérations de marché et des niveaux des normes américaines fédérales et californiennes. Par exemple, GM a annoncé récemment que les gros modèles à moteur diesel ne seraient pas vendus en Californie, car la taille du marché ne justifiait par la mise au point des dispositifs dépolluants nécessaires. À l'heure actuelle, le marché des véhicules à moteur diesel est très faible au Canada (moins de 5 p. 100 des ventes).

Camionnettes

De toutes les modifications proposées qui ont été examinées au cours de l'étude, c'est l'imposition aux camionnettes de normes limitant les émissions de HC, de CO et de NO_x à 1,05, 11,16 et 1,43 g/km qui aurait le moins de répercussions. La plupart des fabricants de camionnettes à moteur à essence emploient déjà une version similaire ou ajustée des systèmes dépolluants conformes à la réglementation fédérale américaine et se serviraient de ces systèmes pour satisfaire aux normes.

Les augmentations du prix de détail seront de l'ordre de 50 $ pour défrayer l'ajustement des systèmes, qui consistera principalement à accroître le volume des catalyseurs. On ne prévoit aucune répercussion sur la consommation d'essence, l'entretien, la conduisabilité et la durabilité.

Les fabricants de modèles à moteur diesel n'auront à effectuer aucune modification, car le moteur diesel actuel permet de satisfaire aux nouvelles normes.

Des normes plus rigoureuses auraient un effet significatif sur les techniques et les coûts, surtout si elles étaient aussi sévères que pour les véhicules automobiles. En effet, elles seraient alors plus exigeantes que celles qui sont proposées par l'EPA, et les fabricants devraient adopter des systèmes similaires à ceux qui sont employés en Californie.

Autres limites d'émission: automobiles à moteur à essence

À mesure que les normes deviennent plus strictes, les fabricants passent des dispositifs dépolluants non-catalytiques aux systèmes catalytiques d'oxydation ou aux systèmes trifonctionnels américains. À environ 0,93 gramme de HC, 9,3 grammes de CO et 1,24 gramme de NO_x au kilomètre, toutes les voitures, à l'exception des très petites (mini-compactes), seront passées aux systèmes catalytiques. Les coûts plus que les limites techniques établissent ces démarcations. L'injection du carburant en des points multiples à commande électronique ou à commande mécanique en continu, la régulation électronique par ordinateur et les réacteurs thermiques sont des techniques disponibles qui permettraient d'abaisser les émissions. Toutefois, en raison des coûts élevés de ces systèmes et des coûts de mise au point et d'homologation, les dispositifs catalytiques constitueraient une solution plus rentable pour un petit marché comme le Canada.

La démarcation pour le passage aux catalyseurs trifonctionnels serait autour de 0,93 g/km pour les NO_x. Encore là, des techniques pour abaisser les émissions seraient disponibles surtout pour les voitures compactes et sous-compactes, mais, pour des raisons de coûts, la plupart des fabricants devraient opter pour les systèmes trifonctionnels américains.

Autres limites d'émission: automobiles à moteur diesel

Pour ces voitures, le niveau de 0,93 g/km pour les NO_x constitue une démarcation importante. Des limites plus sévères pourraient entraîner l'élimination des grosses voitures à huit cylindres et obliger la plupart des fabricants à mettre au point des systèmes de recirculation des gaz d'échappement à commande électronique pour remplacer les systèmes à commande mécanique. Comme les marchés des voitures diesel en Amérique du Nord sont peu importants, certains fabricants pourraient abandonner complètement les modèles à moteur diesel. Ce niveau représente également une démarcation pour certains fabricants qui seraient forcés d'utiliser des pièges à particules si des normes pour les particules étaient ajoutées aux normes pour les NO_x.

Autres limites d'émission: camionnettes

À l'origine, si les normes limitant à 1,05, 11,16 et 1,43 g/km les émissions de HC, de CO et de NO_x (1, 7, 18 et 2,3 g/mille) avaient été établies par l'EPA, c'était pour ne pas forcer les constructeurs de camionnettes à recourir aux catalyseurs. Toutefois, beaucoup de fabricants ont quand même décidé d'employer des dispositifs catalytiques. Comme les catalyseurs d'oxydation permettent de réduire beaucoup plus les émissions, les limites pour les camionnettes pourraient être abaissées à environ 0,5, 6,2 et 1,43 g/km respectivement sans que des modifications technologiques importantes soient nécessaires.

Les répercussions de limites plus sévères au Canada qu'aux États-Unis sont évidentes: si les limites fédérales américaines ne sont pas réduites également, la disponibilité des modèles au Canada pourrait être touchée, et beaucoup de fabricants recourraient aux dispositifs dépolluants employés en Californie.

Effets du temps froid sur les émissions

Un certain nombre de stratégies en vue de réduire les émissions par temps froid ont été reconnues, mais aucune d'elles ne représente une solution optimale et même pourrait offrir un avantage suffisant pour qu'on puisse penser à modifier les pratiques actuelles. Ces stratégies sont:

- exiger des essais à basse température;
- modifier la méthode d'essai;
- établir des normes relatives à l'équipement des véhicules;
- établir des essais optionnels par temps froid; et
- exiger l'homologation du système dépolluant pour climat froid.

Effet de modifications de la composition de l'essence sur les émissions

L'EPA et l'industrie automobile s'accordent pour dire que l'additif antidétonant de l'essence, le méthylcyclopentadiénylmanganèse-tricarbonyl (MMT), augmente significativement les émissions d'hydrocarbures. Les auteurs sont d'avis qu'il sera très difficile aux fabricants d'obtenir l'homologation des véhicules aux limites proposées à moins que la norme pour les hydrocarbures soit assouplie pour compenser les augmentations prévues des émissions d'hydrocarbures. Par ailleurs, le risque de défaillance prématurée des détecteurs d'oxygène avec les essences contenant du MMT préoccupe particulièrement les auteurs. L'étude des effets sur les détecteurs effectuée par le Coordinating Research Council (CRC) n'a porté que sur quelques détecteurs de première génération, mais les résultats indiquaient une défaillance accélérée des détecteurs. Ces résultats ont été obtenus avec un échantillon de sept modèles des années 1977 et 1978 qui tous avaient été réglés pour satisfaire aux normes californiennes. Les progrès techniques réalisés depuis ont peut-être permis d'atténuer le problème. Lorsqu'il y a défaillance prématurée du détecteur d'un dispositif catalytique trifonctionnel, la régulation du courant de retour ne se fait plus. À moins que le système de régulation par micro-ordinateur ait été pré-programmé pour ajuster la richesse du mélange lors des défaillances du détecteur, les émissions de CO seront excessives. Par contre, si le système a été pré-programmé pour fonctionner en mélanges pauvres, ce seront alors les émissions de NO_x qui s'échapperont.

La seule autre préoccupation importante de l'industrie touche la composition des carburants diesel. Mercedes-Benz a notamment fait un long commentaire sur la qualité des carburants diesel et ses répercussions sur les émissions et a présenté un rapport technique à ce sujet. Cette compagnie souhaite une réglementation ou des prescriptions strictes concernant la qualité de ces carburants.

La préoccupation de Mercedes-Benz vient de ce qu'elle prévoit que la demande croissante pour les distillats moyens dans d'autres secteurs que les transports (p. ex., l'industrie chimique) pourrait dépasser la production des carburants diesel et des autres distillats moyens par distillation fractionnée du pétrole brut. Cela pourrait obliger les raffineurs à augmenter les constituants plus lourds des carburants diesel et à produire ceux-ci par craquage (thermique, catalytique, etc.) ou reformage d'autres composantes du pétrole brut. Des études commandées par l'EPA ont indiqué qu'initialement l'emploi des bruts synthétiques tirés des sables pétrolifères et du charbon pourrait être sous forme de mélanges directs (avec hydro-traitement) avec des carburants diesel.

1.0 INTRODUCTION

The study described in this report was undertaken as part of the Socio-Economic Impact Analysis (SEIA) of the proposed hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxides (NOx) emission standards of 0.25 HC, 4.35 CO, and 0.62 NOx grams per kilometre (0.41 HC, 7.0 CO, 1.0 NOx grams per mile). The announcement of the proposed standards and that a SEIA would be prepared was made in the CANADA GAZETTE, Part I on September 18, 1982.

The main purposes of the study were to examine the technology required for more stringent control of automobile emissions and to determine the additional costs of the hardware that would be required to meet the more stringent emission standards. The basis for the analyses was existing data. No experimental work, laboratory testing, or other new work was carried out for this study.

In addition to emission control technology and costs, the effects on emissions of: cold weather conditions such as those encountered in Canada and fuel composition were considered.

1.1 Scope of the Work

Initially, the study was to consider three emission levels, the current Canadian standards, the proposed standards, and an intermediate level equivalent to the 1977 United States standards.

Level	Standard - Grams/Kilometre			Standard - Grams/mile		
	HC	CO	NOx	HC	CO	NOx
Current	1.24	15.5	1.92	2.0	25	3.1
Interm.	0.93	9.3	1.24	1.5	15	2.0
Proposed	0.24	4.35	0.62	0.41	7	1.0

No distinction was made in the original terms of reference between diesel and gasoline engines and between passenger cars and light trucks. However, after the study started, the scope of work was modified and expanded at the request of the Project Review Group overseeing the SEIA studies.

The first change that was made was to drop the intermediate standards from consideration and instead to examine the emission levels at which widespread use of oxidation catalysts becomes necessary and the levels at which three-way catalysts become necessary.

The second change was to expand the scope of work so that it included:

- separate standards for light trucks;
- separate standard for diesel NOx;
- diesel particulates; and
- evaporative standards.

1.2 Methodology

Data for the study were collected primarily from three sources: government agencies such as Environment Canada, Transport Canada, and the United States Environmental Protection Agency; the open literature; and motor vehicle manufacturers.

Two sources of data from motor vehicle manufacturers were used in the analysis. The first is the replies to the September 18, 1982 Canada Gazette announcement and to the previous announcement of February 20, 1982 regarding the preparation of a SEIA for NOx, only.

The second is the replies that were received to a comprehensive questionnaire that the motor vehicle manufacturers were asked to complete. (A sample of the questionnaire is attached as an Appendix). All of the domestic automobile manufacturers and a sample of importers --- Honda, Toyota, Volkswagen, and Jaguar Rover Triumph were asked to submit the data outlined in the questionnaire. American Motors and Jaguar Rover Triumph did not provide responses to the questionnaire. All of the remaining manufacturers and importers returned questionnaires of varying degrees of completion. Where appropriate follow-up meetings were held with the manufacturers to discuss their input.

All of the remaining importers that made submissions subsequent to the Canada Gazette announcements were contacted by mail and sent questionnaires which they were invited to complete and/or submit any other relevant data.

1.3 Contents of the Report

The emission control technology and costs to meet current and proposed emission control standards are discussed in Chapter 2 and Chapter 3 respectively.

Alternate emission control standards are considered in Chapter 4.

A review of cold weather effects on emissions is contained in Chapter 5.

The fuel composition issues are discussed in Chapter 6.

2.0 EMISSION CONTROL TECHNOLOGY TO MEET CURRENT STANDARDS

2.1 Current Control Technology Usage in Gasoline-Engined Passenger Cars

2.11 General Approaches

Four basic types of emission control systems are used to meet the current emissions standards of 1.24 HC, 15.5 CO, 1.92 NOx grams per kilometre (2.0 HC, 25 CO, 3.1 NOx grams per mile):

1. Non-Catalyst

The typical system in this category uses enleanment of air/fuel ratio, exhaust gas recirculation (EGR), and, usually, injection or aspiration of air into the exhaust manifold using either belt driven air pumps or pulse air (reed valve) devices. Non-feedback carburetors or mechanical fuel injection (low pressure, manifold) are generally used for fuel metering. Electronic (multi-point, manifold) fuel injection systems are occasionally used in luxury or high performance models. Compared to pre-emission control engines, engine modifications (such as reduced compression ratio, revised combustion chamber geometry, retarded spark timing, modified valve overlap, modified intake and exhaust manifolds, etc.) are common. Breakerless high energy ignition and heated intake manifolds (early fuel evaporation) are also commonly used.

2. Oxidation Catalyst

The typical system in this category uses the same components as in the non-catalyst system above, except, an oxidation catalyst is added.

3. U.S. Federal System

The typical system in this category uses the emission control system employed by the manufacturer to meet the 1983 U.S. federal emission control standards of .25 HC, 2.1 CO, 0.62 NOx grams per kilometre (.41 HC, 3.4 CO, 1.0 NOx in grams/mile). Usually this system uses a three-way catalyst or three-way plus oxidation catalyst in conjunction with electronically-controlled feed-back fuel management. The latter consists of an electronic control module, oxygen sensor, and a means of providing variable air fuel ratio control, such as, variable jet carburetor or electronic fuel injection (throttle body or multi-point). In some cases, the electronic control system is expanded to provide electronic control of spark timing, EGR, and air injection. Air injection is also common on these systems. These systems offer substantially more emission control margin than necessary for the current Canadian standards.

4- Special

A few manufacturers offer models with unique approaches to the control of emissions, such as, the stratified charge engine (CVCC) of Honda, the NAPS-Z engine of Nissan, and the MCA-Jet offered by Mitsubishi. In general, these systems offer greater emission control margin than necessary for the current Canadian standards.

2.12 Emission Control Technology Usage As Reported by Manufacturers

It was requested in the questionnaire that manufacturers provide detailed descriptions of the emission control hardware and systems used to meet current emission standards. Only in a few cases did the manufacturers provide this information in detail. Some manufacturers provided verbal descriptions during interviews, while others provided some information in submissions responding to the Canada Gazette notice. A summary of the responses follows:

BMW AG

BMW reported that it uses the U.S. federal emission control systems exclusively on all models sold in Canada.

Chrysler Canada Ltd.

In discussions with Chrysler, it was reported that most four cylinder engines, representing about 80% of Chrysler production, utilize a non-catalyst system consisting of EGR, air pump, standard carburetor with air/fuel enleanment, and high energy ignition. A 1.6 litre 4-cylinder engine and the 6 and 8 cylinder models employ oxidation catalyst systems.

Ford Motor Company of Canada, Ltd.

Ford Motor Company currently uses non-electronic, oxidation catalyst systems on the majority of their production. Assuming the current emission standards remain unchanged, Ford projected the following mix of emission control technology for unique Canadian calibrations in 1986:

Hardware	Percent Usage
Air Injection	51%
Air Aspiration	11%
Exhaust Gas Recirculation	80%
Electronic Fuel Injection (Multi-point)	21%
Electronic Fuel Injection (Throttle Body)	39%
Oxidation Catalyst	43%
Three-way Catalyst	23%
Three-way plus Oxidation Catalyst	14%
Micro-computer Control	60%
Non-Feedback Carburetor	40%
Evaporative Emissions Control	57%

General Motors of Canada Ltd.

For the vast majority of General Motors vehicles sold in Canada, GM uses two emission control system types to meet the current standards: one a unique Canadian system employing an oxidation catalyst and the other, a U.S. federal system employing closed loop electronic fuel management and a three-way plus oxidation catalyst. The oxidation catalyst is used on 93% of production. Approximately 5% of production, consisting mainly of low production or high performance models, uses the U.S. federal system.

The details for the systems that use catalysts are:

Hardware	Percent Usage Oxidation Catalyst	U.S. Federal
Engine Modifications	100%	100%
Air Injection	nil	100%
Air/Fuel Enleanment	100%	nil
Exhaust Gas Recirculation	100%	100%
High Energy Ignition	100%	100%
Throttle Body Fuel Injection	nil	46%
Feed-back Carburetor	nil	54%
Micro-Computer Control	nil	100%
Oxidation Catalyst	100%	nil
3-Way plus Oxidation Catalyst	nil	100%
Evaporative Emissions Control	100%	100%

The remaining 2% of General Motors' Canadian sales are made up of a Chevette model that uses a lead-tolerant emission control system and a small number of light duty vehicles that require unleaded fuel, but do not use a catalyst in the emission control system.

If current emission control standards are maintained, General Motors has indicated it has the option of using an open loop electronic emission control system for the post-1985 calibrations. Such a system would be based on the U.S. closed loop emission control system, but the oxygen sensor and three-way catalyst would not be required. Reduced fuel consumption could be achieved by using the open loop electronic emission control system.

Honda Canada Inc.

Honda reported that it uses a non-catalyst approach on 96% of production with about 25% of production incorporating the CVCC (stratified charge engine). Details of emission control hardware usage are:

Hardware	Percent Usage
Engine Modifications	100 %
Air Induction	36.2%
Pulse Air	3.2%
Air/Fuel Enleanment	36.2%
Exhaust Gas Recirculation	13.7%
Oxidation Catalyst	3.2%
Stratified Charge	25.8%
Auto-choke	46.6%
Deceleration Device	96.9%
Evaporative Emissions Control	100 %

Toyota Canada Inc.

Toyota reported that it uses six emission control systems on eight engine families. One of the emission control systems is non-catalyst and is used on one engine family. The balance of the systems are essentially U.S. Federal systems.

The six emission control systems are:

1. Non-catalyst -- using engine modifications, air injection, exhaust gas recirculation.
2. Oxidation Catalyst -- using engine modifications, air injection, exhaust gas recirculation, and oxidation catalyst.
3. U.S. Federal -- using engine modifications, air injection, exhaust gas recirculation, feedback carburetor, and three-way plus oxidation catalyst.
4. U.S. Federal -- using engine modifications, multi-point electronic fuel injection, computer control, and three-way catalyst.
5. U.S. Federal -- same as 4 but includes exhaust gas recirculation.
6. U.S. Federal -- same as 5 but includes high energy ignition.

All of the Toyota emission control systems include evaporative emissions controls.

Volkswagen Canada Inc.

Volkswagen reported that it uses six different emission control systems for its Volkswagen, Porsche, and Audi models. Three systems are non-catalyst and differ from each other by the addition of EGR or air injection. Three systems are U.S. federal emission control systems which are used on low production volume vehicles.

The Volkswagen emission control systems are as follows:

1- Non-catalyst -- using continuous, multi-point mechanical fuel injection, engine modifications, high energy ignition, and evaporative emissions control.

2- Non-catalyst -- same as one, except, exhaust gas recirculation is added.

3- Non-catalyst -- same as one, except, air injection is added.

4- U.S. federal -- using continuous, closed loop, multi-point mechanical fuel injection, engine modifications, high energy ignition, computer control module, three-way catalyst and evaporative emissions control.

5- U.S. federal -- same as four, except, multi-point electronic fuel injection is used instead of mechanical fuel injection.

6- U.S. federal -- same as five, except, air injection is added.

The percent usage by Volkswagen for individual items of emission control hardware are:

Emission Control Hardware	% of Production
Engine Modifications	100
Air Injection	0.5
Exhaust Gas Recirculation	21
High Energy Ignition	100
Electronic Multi-point Fuel Injection	3
Mechanical Multi-point Fuel Injection	97
Micro-computer Closed Loop Control	13
Three-way Catalyst	13
Evaporative Emissions Control	100

2.2 Current Control Technology Usage in Diesel-Engined Passenger Cars

2.21 General Approaches

The diesel engine is an unthrottled engine employing a heterogeneous air/fuel mixture for combustion. As a result, the diesel operates with excess air and flame quench effects near combustion chamber surfaces are minimal compared to the gasoline engine that operates on a homogeneous air/fuel charge. As a result, the diesel engine is an inherently low emitter of hydrocarbons and carbon monoxide. Therefore, the current HC and CO emission standards are usually easily attained by diesel engines.

The combination of high compression ratio, higher heating values for diesel fuels, and heterogeneous air/fuel charge, are characteristics that promote NOx formation, thereby, making NOx emissions the primary emission control consideration for the diesel engine. However, at the current NOx standard few diesels, if any, require any emissions controls, especially, since some automotive diesels employ divided chambers. Divided chamber or precombustion chamber diesel engines produce lower combustion temperatures and, thus, lower NOx emissions because combustion takes place in two steps. Ignition is initiated with a rich air/fuel mixture in a small chamber; after which the ignited mixture is rapidly mixed with excess air in the main chamber, where combustion is completed under lean air/fuel conditions.

There is general agreement amongst emission control technology specialists that the diesel engine has little difficulty in attaining NOx standards that are no more stringent than 1.24 g/km (2.0 g/mi). If there were need to control NOx emissions at these levels, application of modest fuel injection retard or use of valve timing changes to promote internal EGR or injector redesign are steps that could be taken to provide adequate control.

In addition to gaseous emissions, there are concerns with smoke, odour, and particulate emissions from the diesel engine. The U.S. EPA has promulgated regulations setting particulate emissions standards for the light duty diesel-powered vehicle of 0.37 g/km (0.6 g/mi) effective with the 1982 model year and 0.12 g/km (0.2 g/mi) for 1987 and subsequent model years. Smoke and particulate emissions from the diesel are attributable to incomplete combustion or pyrolysis of large droplets of fuel in the injection spray, wet fuel sprayed on combustion chamber or piston surfaces, and droplets of fuel that continue to dribble from the injectors after injection. Odour is attributable to the high aromatic content of diesel fuel, as many of the partially oxygenated aromatic by-products of combustion are quite odouriferous.

Smoke, odour, and particulate emissions have been greatly reduced through the use of low sac fuel injectors, redesign of injector spray cone angles and combustion chamber geometry, and, in some cases, through the use of divided chambers. Unfortunately, as will be discussed later, some of the NOx control techniques, such as, retarded injection timing, increase particulate loadings in the exhaust.

Given the low sales volume of diesel cars and the fact that the current emission standards present little problem for the diesel, the diesel-engined passenger cars offered for sale in Canada are usually "country of origin" models (European, Japanese or U.S.versions).

2.22 Emission Control Technology Usage as Reported by Manufacturers

While many manufacturers discussed the ramifications of reducing the NOx emission standard for their diesel-engined product lines, only Volkswagen provided details on emission control hardware usage. Volkswagen responded that their "current diesel is an optimized design using no additional hardware".

2.3 Current Technology Usage in Light-Duty Trucks

The general trend of emission control technology usage, found for automobiles, also, holds true for light-duty trucks. Unique Canadian systems are used whenever production volumes are large enough to justify special systems. Otherwise, the U.S. federal systems for light-duty trucks are used. Thus, two types of emissions control systems are currently utilized: a non-catalyst system and an oxidation catalyst system. The hardware composition of these systems is as already described above for automobiles. Since the U.S. EPA standards for light trucks are 1.05 HC, 11.16 CO, 1.43 NOx g/km (1.7 HC, 18 CO, 2.3 NOx in g/mi), the usage of severe NOx control measures, such as the three-way catalyst is unnecessary.

Only General Motors, Volkswagen and Toyota provided details on emission control technology usage in light-duty trucks. Their reports were:

General Motors of Canada Ltd.

General Motors uses an oxidation catalyst system across the entire light-duty truck fleet. This system consists of engine modifications, air/fuel enleanment, exhaust gas recirculation, high energy ignition, oxidation catalyst, and evaporative emissions control. Air injection is also used on 68% of production.

Toyota Canada Inc.

Toyota reported using engine modifications, air injection, exhaust gas recirculation, high energy ignition, oxidation catalyst, and evaporative emissions control on their light-duty truck models.

Volkswagen Canada Inc.

Volkswagen uses two systems on their light trucks, a mechanical fuel injection, non-catalyst system and a closed loop, three-way catalyst system employing electronic fuel injection. Both systems employ engine modifications, high energy ignition and evaporative emissions control. The non-catalyst system uses EGR for NOx control.

2.4 Evaluation of Current Emission Control Technology Usage

The terms of reference for this study required identification of the emission control technology needed to meet the current standards as opposed to the systems used by the manufacturers.

The current Canadian standards of 1.24 HC, 15.5 CO, 1.92 NOx g/km (2 HC, 25 CO, 3.1 NOx g/mi) are less stringent than the 1975 U.S. federal standards (1.5 HC, 15 CO, 3.1 NOx g/mi). No catalysts were used by the industry prior to the 1975 standards, which was the level of control stringency that resulted in the first introduction of catalyst usage in the U.S. Therefore, from a technical consideration, the current standards could be met with a non-catalyst system that employs a combination of spark timing retard, exhaust gas recirculation, air/fuel enleanment, and in some cases, some form of manifold air injection (air pump or pulse air). Carburetor enleanment reduces CO and, to a lesser degree, HC, while spark retard and EGR reduce NOx emissions. However, excessive enleanment, spark retard and EGR can cause increases in engine-out HC emissions. To counter-balance this increase, combustion in the exhaust manifolds is promoted through injection of air.

Since the emission standards are measured as weight of emissions per unit distance travelled, the standards are discriminate against higher inertial weight vehicles and larger displacement engines. As a general rule, lighter vehicles and smaller displacement engines can use less stringent calibrations than heavier vehicles and larger displacement engines, i.e, less spark retard, lower EGR rates, and, often, no requirement for air injection. Thus, many light weight vehicles with 4 cylinder engines could meet the current standards with enleanment, EGR, and spark retard. Some 6 and 8 cylinder engines in heavier vehicles could meet the standards with the addition of manifold air injection.

In the early 1970's manufacturers employing this basic emission control approach experienced substantial fuel consumption penalties until the delicate trade-off between EGR rate, air/fuel ratio, and spark timing became more fully understood. Also, better methods of modulating EGR were developed which provide good proportional control of EGR with engine load. Given adequate resources and time a manufacturer can optimize these variables so that little, if any, fuel penalty (at the current standards) is experienced compared to a non-controlled engine. As precise fuel metering is necessary to obtain the optimum air/fuel ratios, advanced fuel metering systems employing electronic or mechanical multi-point injection are often found on non-catalyst emission control systems.

The growing availability and lower cost of electronic computers, electronic fuel injection systems and mechanical/electrical actuators makes it possible to pre-program precise control of air/fuel, EGR, and spark timing. Therefore, if the current standards are retained and sufficient market incentives exist (i.e. a demand for better fuel consumption and lead-tolerant systems), non-catalyst systems could be improved to provide 1-2 percent improvement in fuel consumption (primarily the benefits of electronics and increased compression ratio) and could be the system of choice for most manufacturers.

Other secondary items of emission control hardware are commonly employed along with the basic system, including, quick response chokes to reduce CO and HC during cold start, quick warm-up intake manifolds to alleviate fuel wetting of intake system walls during cold start to reduce CO and HC, high energy ignition systems to eliminate misfire at lean air/fuel conditions, deceleration devices that crack the throttle slightly open during deceleration to eliminates lean misfire in this engine mode and reduce HC emissions, and various valves and devices to modulate EGR and air injection sequences and rates.

The main disadvantage of the non-catalyst system is that it takes time and engineering resources to develop and certify the precise calibrations necessary to maintain good fuel consumption characteristics. The main advantages of a non-catalyst system are that hardware costs are lower and the system allows the use of less expensive leaded gasoline. However, if electronic fuel metering and other electronic controls are used the cost advantage might diminish.

If time and engineering resources are limited and good fuel consumption is a prime objective, an excellent emissions control approach is the use of an oxidation catalyst. There is an excellent experience and compliance data base available on U.S. federal systems for the model years 1975 through 1980 that can be used as guidelines for Canadian calibrations. Since a catalyst is capable of reducing engine-out emissions by 90+ percent, it can be used as the primary means of HC and CO control at the current standards, thus, allowing the powertrain designer to optimize the engine parameters for good fuel consumption and driveability. Most important, there is a wide range of catalyst compositions, loadings, and volumes to match virtually any engine-out condition. The use of EGR with the catalyst provides the required NOx control.

The main disadvantages of the oxidation catalyst system are the need for consumers to buy more costly unleaded fuel and the additional cost of the catalyst.

Approximately 5 percent of current emission control system useage incorporates some variation of the three-way catalyst system and, of course, this system provides much greater margin of NOx control than is necessary at the current standard. The explanation for this anomaly by the manufacturers is that cost considerations require the use of this U.S.system in Canada on low production volume models. In this case, the production volume is so low that the engineering, development, and compliance costs for a unique Canadian calibration would exceed the added hardware costs of the three-way catalyst system. For example, Chrysler reported that the added cost for a closed loop three-way catalyst system over an oxidation catalyst baseline was $210 for their 2.2 litre engine. With certification costs around $250,000 per emission control system configuration, Chrysler would have to sell over 1000 units just to recover the certification costs associated with the development of a unique Canadian model. Additional sales would be needed to recover development, tooling, and other one-time costs.

Other emission control systems, in various stages of development, could be considered for use at the current standards. These systems include the thermal reactor, the stratified charge engine, the lead-tolerant catalyst system, and fast burn concepts. However, based on discussions with the industry, only extraordinary circumstances would justify the voluntary expenditure of resources by industry to develop and certify these systems for unique Canadian applications. The thermal reactor has been extensively studied, especially by the manufacturers of tetraethyl lead fuel additives, because it is simple in concept and is lead-tolerant. The main problem has been that fuel enrichment and/or spark retard has been required to maintain the operating temperature of the thermal reactor with the result that fuel consumption characteristics have been poor. Recent studies with lean reactors and operational techniques during startup have indicated that improvements in fuel consumption are possible.

The stratified charge engine has not been widely used (except Honda) because the engine is unable to attain the most stringent standards used in the U.S. without the use of a catalyst. The addition of a catalyst to the stratified charge engine would make the system more expensive than a conventional engine with catalyst.

Lead-tolerant catalysts have been studied in North America, but, the main developments have taken place in Europe. If the lead-tolerant catalyst is successfully developed and utilized in Europe, the system could be a feasible candidate at current Canadian standards. In fact, several manufacturers have stated that, if the European Community adopts more stringent standards, the European emission control systems could find application in Canada and other parts of the world.

In summary, a non-catalyst emission control system has sufficient emission control margin to allow most manufacturers to meet current Canadian emission control standards. However, if time, and human resources are limited and good fuel consumption is an important goal, the oxidation catalyst is a more cost-effective option for many manufacturers. The choice of a three-way catalyst system, or more correctly, a U.S. federal emission control system, is dictated solely by production volume considerations, and this system would be selected whenever costs for development, certification, and compliance of a unique Canadian system exceed the costs of a U.S. federal system.

2.5 Costs of Current Emission Control Technology

2.51 Sources of Data

The automotive manufacturing industry considers the costs of emission control hardware to be sensitive and proprietary information. In addition, the complexity of determining individual emission control component costs compounded by the multitude of emission control system calibrations offered by a manufacturer makes it difficult even for a manufacturer to generate detailed information on a retail price equivalent basis. This complexity is caused by the variability in a large number of direct and indirect cost factors including:

- variations in design for a given hardware item, such as, differences in materials of construction, method of manufacture, and performance specifications;
- the difficulty of determining costs for controls that are primarily redesign or recalibration, such as, engine modifications involving combustion chamber geometry;
- large variations in production volume between manufacturers, carlines, and models;
- variation in sources of supply, for example, different countries of origin, and in-house manufacture versus outside purchase;
- Variations in cost accounting practices and methods of allocation for direct and indirect cost burdens, research and development costs and compliance costs. For example, the cost accounting and allocation of costs associated with the research and development of emission controls vary considerably from one manufacturer to another.
- variations in markup factors for corporate and dealer cost allocations and profit.

The questionnaire submitted to the manufacturers requested detailed cost and retail price equivalent data for individual items of emission control hardware and for total emission control systems. However, the terms of reference of the study did not allow for confidential treatment of individual company cost data and they were asked to submit only information that they were willing to make public. For this reason, and possibly, the factors listed above little cost/price information was received from the industry. Virtually all of the cost/price data that was received has been included in this report.

In fact, there is also little cost information available in the literature, probably, for the same reasons. The most comprehensive source of cost information is the U.S. Environmental Protection Agency (EPA). Under the U.S. Clean Air Act the EPA is required by Congress to make periodic technology and cost assessments. In addition, certain provisions in the act enabling industry to petition the EPA administrator to extend statutory deadlines and to grant waivers created opportunities in the past for EPA to require the industry to submit cost data to support industry applications for extension or waiver. While much of the individual manufacturer's data submitted to EPA contained provisions for EPA to safeguard confidentiality, EPA was able to provide cost data for the purpose of this study.

2.52 The Lindgren EPA Cost Study

In 1977, EPA contracted with LeRoy H. Lindgren, of Rath and Strong, Inc., to develop cost estimation methodology and cost data for emission control hardware. The results of this study published in 1978 (reference 1) provides the most comprehensive source of information in the open literature. Since 1978, EPA has periodically updated the Lindgren data using primarily the methodology developed by Lindgren.

The cost estimation model developed by Lindgren employs a full cost approach as opposed to a differential cost approach. In the full cost method the costs of each emission control component are computed by calculating direct materials and labor costs and then applying a share of the fixed overhead and corporate level costs to derive what Lindgren defines as the "retail price equivalent". Recognizing the complex relationships amongst the automotive manufacturers, the parts supply industry, and the dealer networks, Lindgren defined a three-tier makeup for the industry involving the dealer level, the corporate level, and a manufacturer level. The manufacturer level could be a supplier, vendor, or a division of the corporation. Based on this structure, Lindgren developed the following basic formula:

$$RPE = (\ (DM + DL + OH)(1.4) + TE + LBE\ )(1.8)\ ) + RD + TE$$

Where: RPE = Retail Price Equivalent
DM = Direct Materials
DL = Direct Labor
OH = Fixed and Variable Overhead
TE = Tooling Expense
LBE = Land and Building Expense
RD = Research and Development

In order to account for the Canadian federal sales tax applied at the dealer net price the Lindgren formula would be:

$$RPE = (\ (DM + DL + OH)(1.4) + TE + LBE\ )(\ 1.4 \times 1.09 + 0.4)\ ) + RD + TE$$

The multiplier of 1.4 in the equation provides for markup at the manufacturer level and includes 20% each for supplier allocation and supplier profit. The multiplier of 1.8 provides markup at the corporate and dealer level and includes 20% each for corporate allocation, corporate profit, and 40% for dealer margin. The corporate allocation is to cover its costs to support the manufacturing divisions and dealers; e.g., purchasing, advertising, office administration, salary and benefits administration, etc.

Direct materials entail those materials of which a given component is comprised. Actual weights of components was used by Lindgren where possible and costs of materials were determined from sources such as the American Metal Market. Direct labor includes the cost of laborers directly involved in the fabrication of a given component. The hours per unit were estimated by using standard industrial engineering data and procedures. Overhead includes both fixed and variable components of overhead. Lindgren used a straight 40 percent of the direct labor amount to determine overhead costs.

The Lindgren study provides specific cost estimates of many emission control devices and cost estimation equations, or procedures for others. Costs are very sensitive to production volume, and while Lindgren provides a formula to adjust for production volume differences, the cost values in the report represent production volumes of 350,000 to 1,000,000 units per year. Lindgren's cost estimates will not be presented here because they are in 1977 US dollars and EPA has subsequently up-dated the values to reflect changes in design and inflation.

2.53 U.S. EPA Cost Estimates

EPA has periodically computed emission control technology costs by using Lindgren's methodology and cost estimates as a baseline. For most emission control components, the Lindgren estimates were simply adjusted to account for inflation. For new emission control technology, that has been developed since the Lindgren study, EPA computed the costs using the Lindgren methodology in most cases.

To check these data, EPA also used a discounted aftermarket price approach. In this approach, the aftermarket prices for components are obtained from retailers (e.g. dealer price lists and service estimates) or the manufacturers and these values are discounted to remove the aftermarket parts markup. Lindgren's study suggested a discount factor of 0.3, that is, the aftermarket price is multiplied by 0.3 to obtain the OEM retail price equivalent. Finally, information received in response to the CO Waiver Cost Information Subpoena was used to further check the EPA estimates. Unfortunately, the individual data submitted by the manufacturers is proprietary and not available to the public.

To provide retail price equivalent estimates for electronic control units and electronic spark advance systems the EPA used only the discounted aftermarket price approach. The EPA estimates (in 1980 U.S. dollars) are for 1983 systems and account for changes in electronics technology since the initial estimates were made in 1977.

The latest EPA estimated retail price equivalents (reference 2) for emission control components are summarized in Table 2-1. The costs are reported in 1980 U.S.Dollars in the reference and have been converted to 1983 Canadian dollars. The multiplier to convert from 1980 U.S. dollars into 1983 Canadian dollars was calculated using the following data:

- Automobile purchase component of the Consumer Price Index for Canada:
  - June 1980 ---- 88.8
  - June 1983 ---- 108.4

- Average Canada-U.S. exchange rate for 1980:
  - 1.163

- Federal Sales Tax of 9% of the dealer net price. Using the Lindgren markups and estimates the federal sales tax as a percent of the retail price equivalent is:

- 6.3%

Therefore the multiplier is:

$$\$ \text{ U.S} \times 108.4/88.8 \times 1.169 \times (1 + 6.3/(100 - 6.3)) = \$ \text{ CDN}$$

or

$$\$ \text{ U.S.} \times 1.52 = \$ \text{ CDN}$$

The costs for catalysts are not included in table 2-1 for a number of reasons. There is no single generic price for an automotive catalyst because the volume of the catalyst, the noble metals composition and content, the type of substrate, and geometric configuration varies considerably with the function of the catalyst (oxidation, reduction, 3-way), the emission control level required, the mix of other emission control hardware installed (e.g. air vs. non-air, EGR, type of fuel management, etc.) and the characteristics of the powertrain application (e.g. number of cylinders, displacement, etc.). EPA has calculated costs for a range of catalyst types, sizes and applications.

The general equation that EPA used to compute catalyst costs follows the form:

$$RPE = (Cc + Cs)(m) + Ci$$

where:

RPE = Retail Price Equivalent
Cc = Cost of noble metals
Cs = Cost of structural materials
m = Corporate markup multiplier
Ci = Related capital investment

Table 2-2 provides EPA retail price equivalent estimates for a number of catalysts that were used in systems designed to meet 1981 U.S. emission standards (0.41 HC, 3.4 CO and 1.0 NOx g/mi). Table 2-2 also provides the total retail price equivalent for the total emission control system. For this estimate EPA assumed that one-half of the fleet was comprised of vehicles utilizing four-cylinder engines and the other half of the fleet was equipped with six cylinder engines. While all the systems are targeted for the same emission control level, there is a wide range of catalyst types and associated costs.

TABLE 2-1

U.S. EPA ESTIMATED RETAIL PRICE EQUIVALENT OF EMISSION CONTROL COMPONENTS AND SYSTEMS (1983 CANADIAN DOLLARS)

Component	Retail Price Equivalent
Exhaust Gas Recirculation Valve (EGR)	$ 13.15
Air Injection System	59.69
Pulse Air Injection System	8.68
Air Switching Valve	3.80
Thermal Vacuum Switch	6.36
Electric Choke	7.62
Feed Back Throttle Body Fuel Injection	109.84
Standard Carburetor (two barrel)	46.09
Feedback Carburetor (cost above std.carb.)	15.13
Electronic Computer Control Unit	128.71
Electronic Spark Advance	45.60
Oxygen Sensor	15.20
Electronic EGR Pintle Position Sensor	15.49
Sonic Electronic EGR valve	14.30
Coolant Temperature Sensor	11.21
Inlet Air Temperature Sensor	11.21
Engine Speed Sensor	7.60
Crank Angle Position Sensor	3.35
Throttle Position Sensor	3.35
Positive Crankcase Ventilation (PCV) Valve	1.90
High Energy Ignition	13.30
Early Fuel Evaporation System (EFE)	7.60
Stainless Steel Exhaust Pipe	17.10
Evaporative Control System	16.72
Thermal Reactor (4 cylinder)	73.47
(6 cylinder)	96.98

Source: EPA -- Reference 2

TABLE 2-2

EPA ESTIMATED

CATALYST AND EMISSION CONTROL SYSTEM RETAIL PRICE EQUIVALENTS

(In 1983 Canadian Dollars*)

Emission Control System	Catalyst Cost	Total System Price
1. FBC/3W + OC/CEGR/AIR	$ 290	$ 630
2. FTB/3W/CEGR/AIR	250	640
3. FTB/OC/EEGR/AIR	170	580
4. OLC/3W + OC/CEGR/AIR	220	420
5. FBC/3W/CEGR/NAIR	160	440
6. OLC/3W/CEGR/AIR	220	420
7. OLC/3W/CEGR/PAIR	220	370
8. OLC/OC/CEGR/AIR	190	390
9. OLC/OC/CEGR/PAIR	240	380
10.OLC/TR/CEGR/AIR	--	250
11.FBC/3W/CEGR/AIR	150	490
12.FBC/3W/CEGR/PAIR	170	470
13.OLC/OC/CEGR/NAIR	260	390

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* Rounded to nearest $ 10

Abbreviations:

AIR = Air Injection Reactor (air pump)
CEGR = Conventional Exhaust Gas Recirculation
EEGR = Electronic Exhaust Gas Recirculation
FBC = Feedback Carburetor
FTB = Feedback Throttle Body Injection
NAIR = No Air Injection
OLC = Open Loop Carburetor
OC = Oxidation Catalyst
PAIR = Pulse Air Injection System
3W = Three-way Catalyst
3W + OC = Three-way plus Oxidation Catalyst
TR = Thermal Reactor

Source: EPA -- Reference 2

2.54 Baseline Cost Estimates for Current Emission Control Systems

A main objective of the questionnaire was to obtain baseline cost estimates for the emission control hardware that is currently utilized in Canada. Because the the definition of cost varies considerably, depending upon the cost accounting principles and the definitions employed, the manufacturers were requested to report costs for emission control hardware as the aggregate of the following cost components:

- out-of-pocket cost for purchased components, parts, etc.;
- direct material costs;
- direct labor; and,
- direct overhead for labor and materials.

In addition, the manufacturers were requested to provide a markup factor that included the balance of the cost components, including as appropriate, indirect costs and burdens, general and administrative expenses, and profits.

For reasons already discussed, a minimal amount of cost information was submitted by industry.

Toyota provided a detailed consumer cost estimate for the emission control systems that they currently use on their models. (The definition of retail price equivalent is the cost to the consumer. Therefore, Toyota's "consumer cost" estimates are comparable to retail price equivalents estimated using the Lindgren methodology). These costs, expressed in 1983 Canadian dollars, are:

System	Consumer Cost
Sub-Compacts	
1. Non-Catalyst (EM,AI,EGR,EVA)	$ 182
2. Oxidation Catalyst (EM,AI,EGR,OC,EVA)	227
3. Three-way/Ox Catalyst-Feedback Carburetor (EM,AI,EGR,FBC,TWO,EVA)	679
4. Three-way Catalyst-Fuel Injection (EM,EFIM,TWC,CC,EVA)	859
5. Three-way Catalyst-Fuel Injection-EGR (EM,EGR,EFIM,TWC,CC,EVA)	631
6. Three-way Catalyst-Fuel Injection-EGR-HEI (EM,EGR,EFIM,TWC,CC,EVA,HEI)	1245
Compact	
1. Three-way Catalyst-Fuel Injection (EM,EGR,EFIM,TWC,CC,EVA)	753
Light-duty Trucks	
1. Oxidation Catalyst (EM,AI,EGR,HEI,OC,EVA)	433

System	Consumer Cost
Diesel-fueled Engine	
1. EM,RT,HPI	107

Abbreviations:

AI = Air Injection
EFIM = Electronic Fuel Injection (multi-point)
EVA = Evaporative Emission Controls
HEI = High Energy Ignition
OC = Oxidation Catalyst
TWC = 3-way Catalyst
CC = Computer Control
EGR = Exhaust Gas Recirculation
EM = Engine Modifications
FBC = Feedback Carburetor
HPI = High Pressure Injection
RT = Retarded Injection timing
TWO = 3-way/ox Catalyst

Honda provided retail price equivalents for individual items of emission control hardware. These costs, based on an exchange rate of 210 yen per 1983 Canadian dollar and rounded to the nearest five dollars, are:

Hardware	Cost
Engine Modifications, EM	$ 0-45
Air Injection, AIR	65
Air Aspiration, AR	10
Air/Fuel Enleanment, A/FE	5-30
Exhaust Gas Recirculation, EGR	20-105
Oxidation Catalyst, OC	285
Stratified Charge	185
Evaporative Emissions Control, EVA	15-35
Auto-Choke, AUTO-C	30-50
Deceleration Device, DECEL	45-65
Piping	10-30

Honda did not add these costs to provide total system costs, but taking the cost estimates and a typical mix of hardware, the following retail price equivalents were computed:

System	Price
1. Non-Catalyst System (EM,EGR,AIR,A/FE,EVA,DECEL,AUTO-C)	$ 120-380
2. Oxidation Catalyst System (EM,EGR,AA,OC,EVA)	330-490

Other manufacturers provided incremental cost data for the additional emission control hardware required to meet the proposed emissions standards. These data will be discussed in subsequent sections of this report.

Based on EPA's data in Tables 2-1 and 2-2 baseline retail price equivalents were computed for a non-catalyst system and an oxidation catalyst system.

EPA's data were converted from 1980 U.S. dollars to 1983 Canadian dollars as previously discussed. These price estimates are:

System	Price
1. Non-Catalyst (EM,AIR,EGR,EVA)	$ 130
2. Oxidation Catalyst System (EM,AIR,EGR,OC,EVA)	$ 390

The EPA estimate for the non-catalyst systems is lower than that of Toyota and Honda, while the EPA cost estimate for a oxidation catalyst system is within the range of the Honda and Toyota estimates. One possible explanation for the lower EPA non-catalyst estimate is that the pricing policies of the manufacturers are designed to reduce the price differentials between the two types of systems. The costs for the technology to meet the proposed standards will be discussed in Section 3 of this report.

3.0 EMISSION CONTROL TECHNOLOGY TO MEET PROPOSED STANDARDS

This section of the report examines:

- The emission control technology, hardware, and systems required to meet the proposed 1986 HC, CO, and NOx emission standards;

- The lead-time needed by the manufacturers to meet the proposed standards;

- The cost, fuel consumption, driveability, and maintenance impacts of the proposed standards;

- The feasibility of establishing a 2 gram SHED evaporative emission standard; and

- The feasibility of establishing a 0.37 or 0.12 grams per kilometre (0.6 or 0.2 g/mile) particulate standard for light-duty diesel-engined vehicles.

The proposed standards of .25 HC, 4.35 CO, .62 NOx grams per kilometre (0.41 HC, 7.0 CO, 1.0 NOx g/mi) for passenger vehicles represent reductions from the current standards of 80%, 71%, and 68%, respectively, for HC, CO, and NOx. The proposed NOx standard represents about a 71% reduction from the uncontrolled level of approximately 2.2 grams per kilometre (3.5 grams per mile).

In the case of light-duty trucks, the proposed standards of 1.05 HC,11.16 CO, 1.43 NOx grams per kilometre (1.7 HC, 18 CO, 2.3 NOx g/mi) represent reductions from the current standards of 15%, 28%, and 26%, respectively, for HC, CO, NOx.

3.1 Passenger Gasoline-Engined Vehicles

3.11 Technical Feasibility

The technical feasibility of attaining the proposed standards is unchallenged by the industry because they have been in effect in the United States since the 1981 model year (except for CO which is more stringent in the U.S.). In fact, for cost reasons already discussed, a small portion (perhaps 5-10%) of Canadian sales already utilize U.S. federal systems that are capable of attaining the proposed standards.

Nevertheless, these standards are difficult to implement, with the most difficult target being the NOx standard. HC and CO emissions are primary by-products of the combustion process and can be altered by changing the combustion conditions and environment, such as, the air/fuel ratio, better fuel preparation and distribution techniques, and combustion chamber configuration. Control techniques that promote combustion efficiency will reduce the emissions of CO and, usually, HC as well. Further, oxidation catalysis is a common and very effective process for controlling CO and HC, even at the extremely dilute reactant concentrations that are present in exhaust gases.

On the other hand, NOx emissions are secondary by-products of combustion, being formed by the reaction between oxygen and nitrogen at the peak temperatures reached during combustion. The large and ever-present concentration of nitrogen in combustion air leaves only two combustion parameters to control, oxygen concentration and combustion temperature. Reducing oxygen concentration (e.g. by enriching the air/fuel mixture) and reducing combustion temperature are the two primary control techniques for NOx. However, to compound the control problem, these techniques may increase HC and CO emissions and may increase fuel consumption.

3.12 Availability of Emission Control Systems for the Proposed Standards

For convenience, NOx control techniques can be grouped into two categories, non-catalytic and catalytic. The non-catalytic controls are already utilized to some extent to comply with the current standards. These techniques include spark timing retard, charge dilution, fast burn, and stratified charge.

Normally, the optimum spark timing program produces a spark several crank degrees before the piston reaches top dead center during the compression stroke. The retardation of spark for emission control purposes delays the spark until the piston is near or after top dead center. Thus, initiation of combustion occurs during the expansion stroke, so that peak combustion temperatures and pressures are reduced. EPA testing of ten 1975 cars indicated that a 3% decrease in NOx emissions is obtained for each degree of spark retard. Unfortunately, fuel economy was also reduced by about 1% for each degree of spark timing. CO emissions were generally higher and changes in HC emissions were mixed. As this technique produces relatively small changes in NOx emissions at a significant expense to fuel consumption, it would not be utilized as a primary NOx control technique to meet the proposed standards.

Charge dilution defines any technique that introduces an inert gas into the air/fuel mixture prior to combustion. These gases include carbon dioxide, water vapour and nitrogen. Since these gases have high specific heats and do not contribute energy during combustion, they effectively reduce peak combustion temperatures and, thus, reduce NOx emissions. The use of exhaust gas recirculation is the most common form of charge dilution as exhaust gas consists primarily of nitrogen, water vapour, and carbon dioxide. Water injection is also a very effective form of charge dilution and reductions of up to 90% have been reported. Fuel consumption improvements were also noted. Water injection is not considered feasible by the industry because of the operational complexities of maintaining a supply of water on-board the vehicle. Excess air (air is 79% nitrogen) can also reduce NOx emissions by up to 43% and is a commonly used technique to meet current standards. It would not be effective at levels below 1.24 grams per kilometre (2.0 grams/mile).

EPA's studies (reference 3) have shown that a substantial number of production vehicles using EGR and oxidation catalysts can attain NOx emissions in the range of 0.31 to 1.24 grams per kilometre (0.5 to 2.0 grams per mile). Figures 3-1 to 3-3 present actual fuel economy versus NOx test data from the EPA studies for vehicles using pulse air (Reed valves), EGR, and oxidation catalysts. Figures 3-4 to 3-6 are similar data for vehicles using air pumps, EGR, and oxidation catalysts. From these studies, it can be concluded that many four cylinder sub-compacts and compacts could meet the proposed standards using the same basic system commonly used to meet current standards. Of course, noble metal loadings and catalyst volumes would have to be increased to handle the more stringent HC and CO standards. Table 3-1 shows the fraction of oxidation catalyst systems used to meet the 1981 U.S. federal standards as a function of vehicle test weight.

Table 3-1
Relative Usage of Emission Control Systems in U.S. for 1981 Model Year
(Source: Reference 3)

System	Test Weight (pounds)			
	2000	2500	3000	Total Fleet
Oxidation Catalyst	.687	.166	.043	.143
Three-Way Catalyst	.313	.826	.957	.805
Diesel	-	.008	-	.052

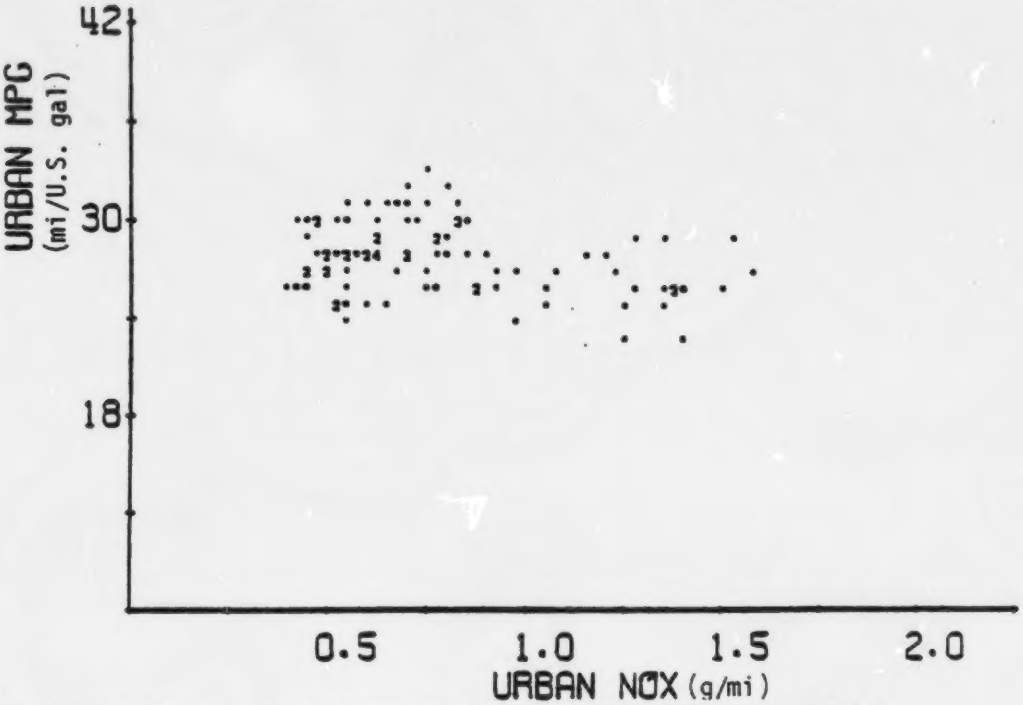
The use of excess air or enleanment also reduces combustion temperature and NOx formation. In the past, lean misfire and slow burning rates limited the dilution tolerances of engines, but, continuing improvements in air/fuel mixture preparation, induction systems, and ignition systems have increased these tolerances. The latest technique for improving dilution tolerance is to increase the burn rate of the air/fuel charge. Dilution can then be increased until the burn rate again becomes limiting. Several methods have been developed to increase burn rate. They include increased swirl and squish, shorter flame paths, and multiple ignition sources. Table 3-2 illustrates some of the early production results using these methods. All vehicles attain NOx emissions of less than .62 grams per kilometre, and, with the exception of Chrysler, all use oxidation catalysts. The percent change in fuel economy is a comparison of the fast burn technology to the sales weighted average fuel economy in the same weight class.

Table 3-2
Results of Fast Burn Applications in Production Vehicles
(Source: Reference 3)

Manufacturer	Engine (L)	Test Weight (Lbs)	+ % MPG	Features
Nissan	2.0	2500	19.8	Two spark plugs Swirl, OC
Mitsubishi	2.6	3000	4.7	MCA-Jet, swirl, OC
Chrysler	2.2	2750	6.4	Squish, short flame path, 3-W + OC
Honda	1.5	2250	13.6	CVCC, OC

FIGURE 3-1

Urban MPG Versus Urban NO_x for
PAIR/EGR/OC Systems at 2500 Pounds ETW*

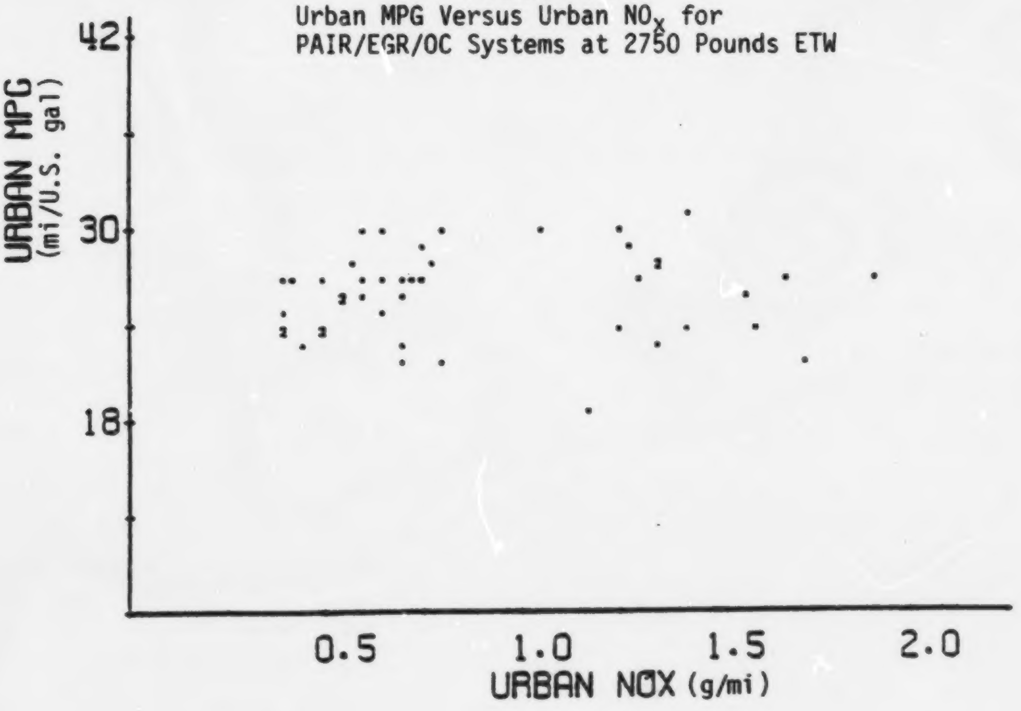


* Abbreviations and their meanings are listed after Figure 3-6

Source: EPA -- Reference 3

FIGURE 3-2

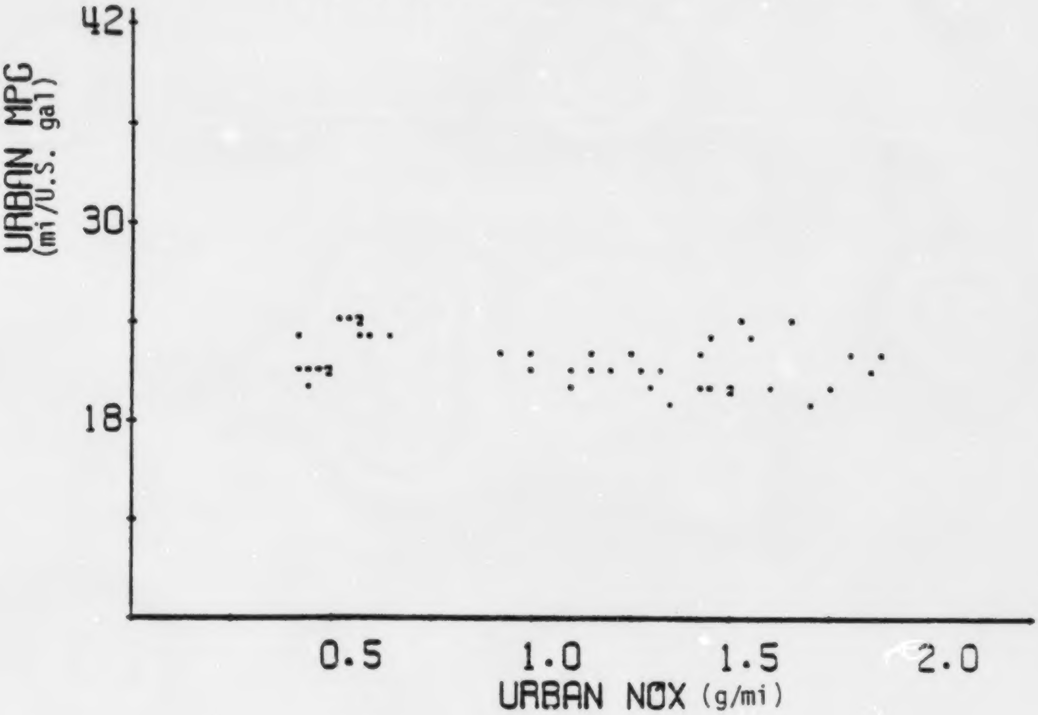
Urban MPG Versus Urban NO_x for
PAIR/EGR/OC Systems at 2750 Pounds ETW



Source: EPA -- Reference 3

FIGURE 3-3

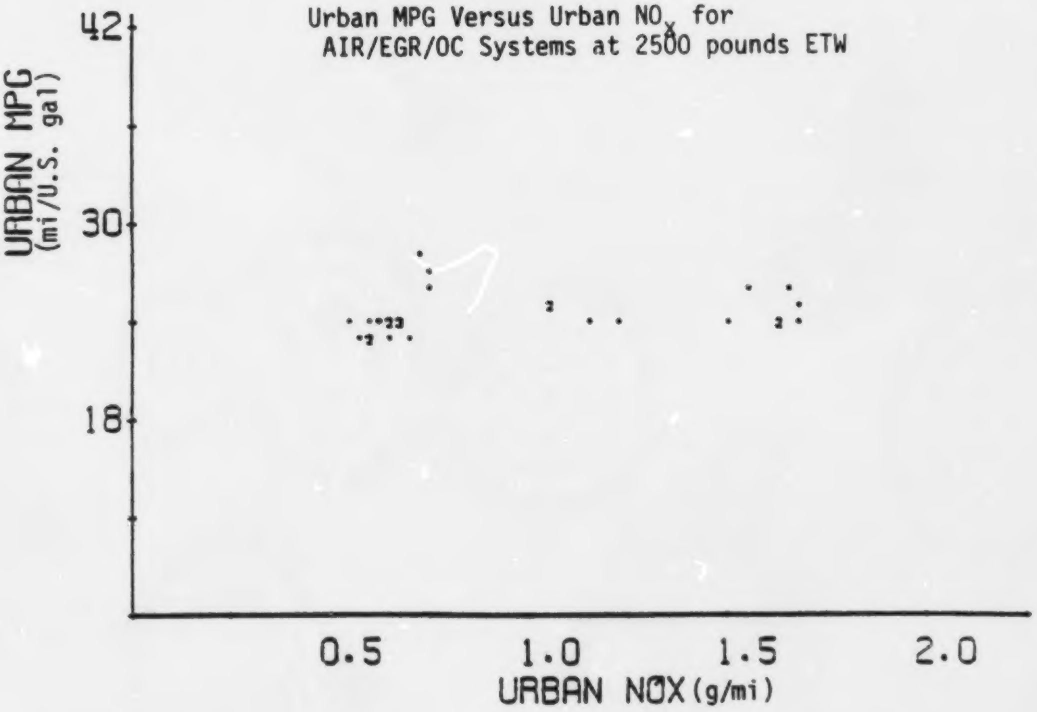
Urban MPG Versus NO_x for
PAIR /EGR/OC Systems at 3000 Pounds ETW



Source: EPA -- Reference 3

FIGURE 3-4

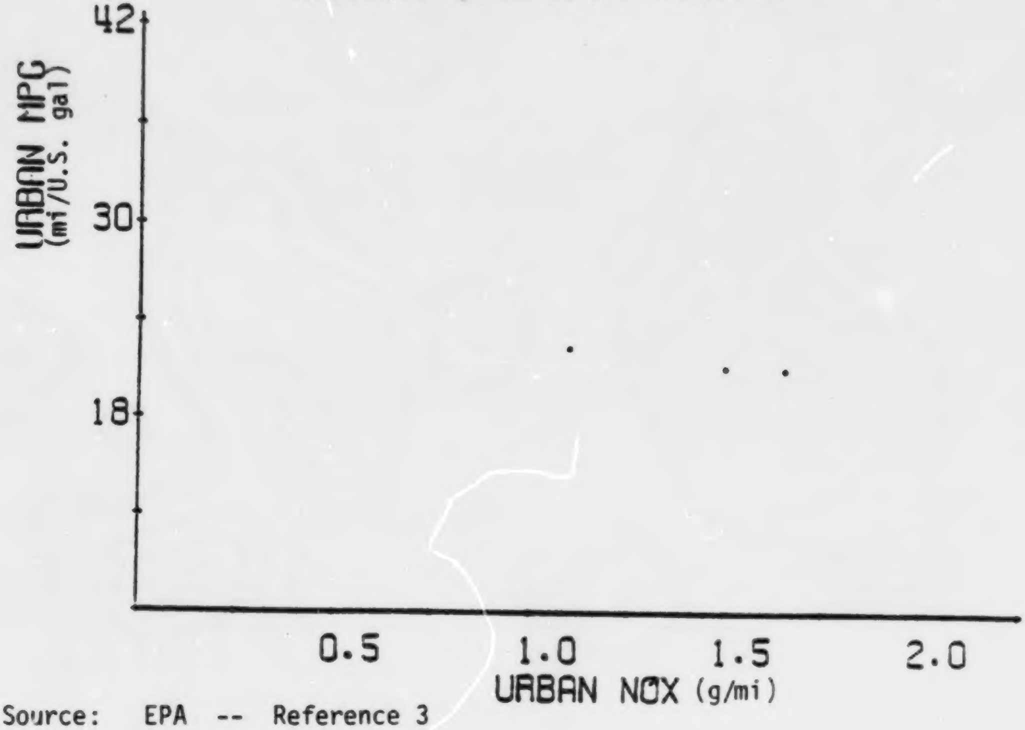
Urban MPG Versus Urban NO_x for
AIR/EGR/OC Systems at 2500 pounds ETW



Source: EPA -- Reference 3

FIGURE 3-5

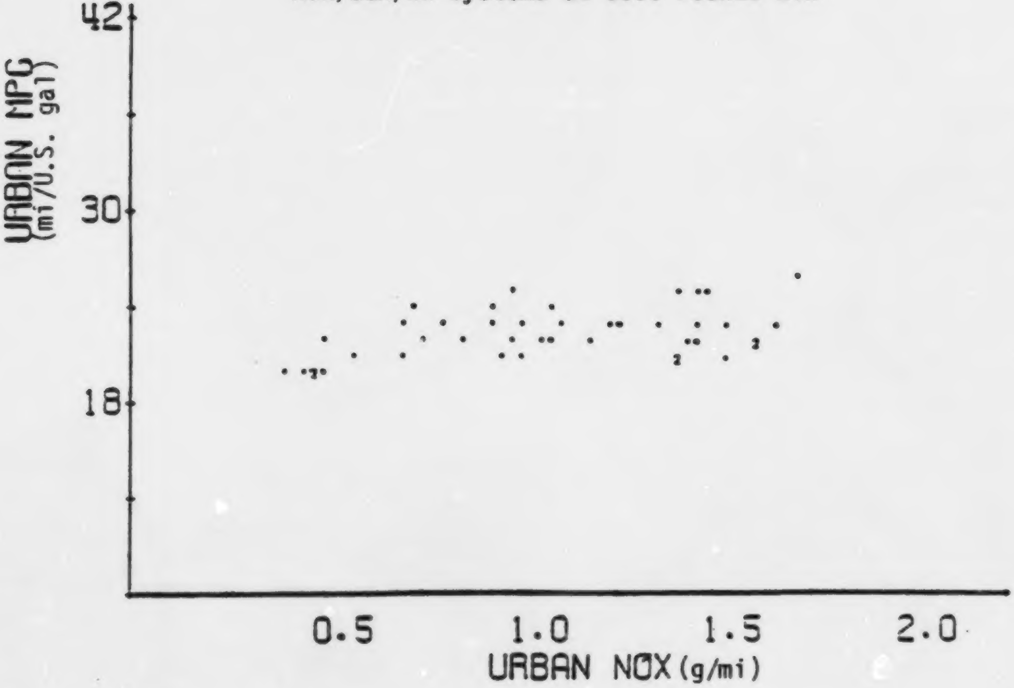
Urban MPG Versus Urban NO_x for AIR/EGR/OC System at 2750 Pounds ETW



Source: EPA -- Reference 3

FIGURE 3-6

Urban MPG versus Urban NO_x for AIR/EGR/OC Systems at 3000 Pounds ETW



Source: EPA -- Reference 3

Abbreviations used in preceding figures 3-1 to 3-6:

AIR = Air Injection Pumps
EGR = Exhaust Gas Recirculation
ETW = Equivalent Test Weight
PAIR = Pulse Air Injection System
OC = Oxidation Catalyst

The last entry in table 3-2 is the only production engine using stratified charge, which is Honda's CVCC engine. Others, such as the Ford Proco and the Texaco TCCS have been extensively studied, but, not introduced into production. All these engines have high dilution tolerances and are capable of NOx reductions in excess of 70%. However, charge dilution tends to increase HC emissions and these engines would have to employ oxidation catalysts to meet the proposed standards.

Six and eight cylinder models and vehicles weighing in excess of 1360 kilograms (3000 pounds) would have to employ catalytic NOx aftertreatment in order to meet the proposed NOx standard. Under reducing chemical conditions (e.g. excess carbon monoxide) certain catalytic materials, such as the noble metals and some base metals, are capable of reducing NOx to elemental nitrogen. These catalytic materials are known as reducing catalysts. If the exhaust concentrations are held close to stoichiometric, some of these catalytic materials, especially Rhodium, will act as a redox catalyst, that is, they will promote oxidation of CO and HC and reduction of NOx simultaneously. (Stoichiometry is a chemistry term referring to the condition where the reactants are present in the exact ratios that are required to allow a reaction to go to completion. Thus, for combustion it means that the ratio of fuel to air is the exact ratio required to produce complete combustion without producing left over fuel or air. An exhaust gas composition is stoichiometric when the reducing components -- hydrocarbons -- balance exactly the oxidizing components -- carbon monoxide and oxides of nitrogen.)

The net chemical reaction becomes:

$$HC + CO + NOx = CO2 + H20 + N2$$

These catalysts are commonly called three-way catalysts. However, regardless of their primary function, the noble metal catalysts are capable of behaving, to some extent, as reduction, oxidation, or three-way catalysts, depending on whether the exhaust conditions are reducing, oxidizing, or stoichiometric. Thus, a three-way catalyst can behave as an oxidizing catalyst if air is injected into the exhaust. Since NOx emissions are mainly a problem under heavy or full load conditions, many three-way catalyst systems are designed to behave as oxidation systems at idle, coastdown, or part-load by the switching on of air injection.

Of course, catalysts can not simultaneously behave as all three types, so if both NOx and CO are problems three-way and oxidizing catalyst beds are often packaged together with provision for air injection between the beds. This is the system referred to as the three-way plus oxidation catalyst system.

NOx reductions in excess of 80% are achievable with three-way catalysts. The NOx control potential of these systems when combined with dilute combustion (obtained, e.g. by exhaust gas recirculation) and precise air/fuel metering is even higher. Reducing catalysts containing base-metal formulations have demonstrated over 75% reduction capability but have not been used in production because of sulfur poisoning problems.

In order to obtain maximum conversion efficiency from a three-way catalyst it is necessary that the exhaust conditions be maintained at or very near stoichiometric. This is achieved through the use of variable air/fuel ratio carburetors or fuel injection systems, oxygen sensors to measure stoichiometry, and micro-computers to monitor the sensors and to control the fuel metering system. These systems are referred to as closed loop, three way systems.

At the present time oxygen sensors can not provide proportional measurement of oxygen concentration in the exhaust. They are limited to measuring the presence or absence of oxygen around the stoichiometric condition. Thus, the fuel metering device is oscillated rich and lean around the stoichiometric point several times a second, with the oxygen sensor, in effect, being used as a high-low limit switch. By biasing the time duration of the oscillations toward either side of the stoichiometric point, the exhaust conditions can be biased slightly rich or slightly lean of the stoichiometric point. Maximum NOx control is obtained with rich bias, whereas more CO control is obtained on the lean side. If excessive rich bias is obtained because of inadequate fuel control or if a three-way catalyst formulation with low CO conversion efficiency is used, it may be necessary to use a follow-on oxidation catalyst. These systems are referred to as closed loop three-way plus oxidation catalyst systems.

If maximum NOx control is not necessary it is possible to use a conventional carburetor or fuel injection system with the three-way catalyst by calibrating the fuel management system near the stoichiometric point under heavy engine load conditions. These systems are referred to as open loop three-way catalyst systems and are mostly limited to use on light weight, four cylinder vehicles with good fuel metering systems.

3.13 Manufacturers' Estimates of Technology to Meet Proposed Standards

The industry comments were uniform in reporting that the closed loop, three-way catalyst system would be required to meet the proposed standards. Individual manufacturer comments on system choices are:

Chrysler Canada Ltd.

Chrysler reported that "adoption of the proposed standards would necessitate much more sophisticated emission control systems, including three way catalysts, oxygen sensors, feed-back carburetors, associated electronics, etc." As an example of their system selection, they described the hardware components for their 2.2 litre passenger cars to include a two bed three-way catalyst (105 cubic inch bed, containing 10 to 1 milligrams per cubic inch of platinum and rhodium, respectively and a 45 cubic inch bed, containing 20 milligrams per cubic inch of palladium), extra heat shielding for the catalyst, air pump with switching, electronic spark advance, and feed-back carburetor.

Ford Motor Company of Canada, Ltd.

Ford reported that the proposed standards would require them "to use the more expensive and complex U.S. federal emission control systems, including electronic controls and three-way plus oxidation catalysts." Ford projects the following mix of emission control technology:

Hardware	Percent Usage
Manifold Air Injection	52%
Exhaust Gas Recirculation	100%
High Energy Ignition	83%
Electronic Fuel Injection (Multipoint)	51%
Electronic Fuel Injection (Single point)	26%
Feedback Carburetor	5%
Non-Feedback Carburetor	18%
Three-way Catalyst	48%
Three-way plus Oxidation Catalyst	52%
Micro-computer Control	83%

General Motors of Canada Ltd.

General Motors would not predict how their control system would change to meet proposed standards in 1986, but indicated that it would probably consist of their current closed loop U.S. federal emission control system with "some refinement anticipated". Currently, this system consists of engine modifications, air injection, EGR, high energy ignition, three-way plus oxidation catalyst, and throttle body electronic fuel injection on 46% of production and feed-back carburetors on the balance of production.

Honda Canada Inc.

Honda reported, that based on their representative 1983 model vehicles, they would plan to meet the proposed standards with engine modifications, air/fuel enleanment, oxidation catalysts, stratified charge engine, air injection, EGR, auto choke, deceleration device, and evaporative emissions control.

Toyota Canada Inc.

In model year 1983, Toyota marketed 11 engine families (eight passenger car and three light-duty truck) in Canada with 9 of these families being the same or slightly modified versions of the U.S. federal system. Toyota reported that the emission control systems for these families would remain basically unchanged if the proposed standards were adopted. The systems for the remaining two engine families would change from non-catalyst or oxidation catalyst systems to three-way catalyst systems.

Volkswagen Canada Inc.

Volkswagen proposes to use three-way catalysts combined with closed loop continuous mechanical or electronic injection fuel management. No EGR was indicated for any of the systems.

Renault USA Inc.

Renault stated that two control systems would be required to meet the proposed standards. Their mini-subcompact of less than 907 kilograms (2000 pounds) would require an oxidation catalyst, air injection, and EGR. Their other vehicles would use a three-way catalyst, oxygen sensor, and feed-back fuel injection.

Peugeot (represented by U.S. Technical Research Company)

Peugeot proposes to use three systems, each incorporating three-way catalysts and pulsair. Two of the systems are closed loop using oxygen sensors with either feed-back carburetor or single point fuel injection. The third system uses a multi-point fuel injection system without feed-back.

3.14 Analysis and Summary of Technology Needed to Meet Proposed Standards

There is clear agreement that the basic emission control approach will be the closed loop, three-way catalyst system. In addition to the catalyst, the typical system will consist of EGR, air injection (pulse air in light vehicles, air pump in the heavy vehicles), oxygen sensor, micro-computer, and feed-back carburetor or electronic fuel injection. More manufacturers will adopt single point electronic injection in place of carburetors because of slightly lower cost and more precise fuel control. Engine modifications, incorporating new fast burn concepts, will be more common. The lightest vehicles could and likely will meet the proposed standards with oxidation catalyst systems. Open loop three-way systems would also be used in some light, four cylinder vehicles.

While some manufacturers have indicated that they will need to use three-way plus oxidation catalyst systems, it is the technical judgement of the authors that the add-on oxidation catalyst is not required with a 4.35 CO grams per kilometre (7.0 CO in grams per mile) standard. The manufacturers also made this judgement during testimony before a U.S. Congressional Committee meeting in 1982 when they argued for a relaxed CO standard (reference 4).

Table 3-3 shows the mix of emission control systems that have been utilized in the U.S. in the model years 1978 to 1983. Starting with the model year 1981, the U.S. HC and NOx standards are the same as proposed for Canada while the U.S. CO standard is lower. The table is further illustration of the system mix to be expected in Canada if the proposed standards are adopted.

Table 3-3

Emission Control System Trends in the United States --- 1978 to 1983

System	Fraction Market Share/ Average Vehicle Weight (Kg)					
	1978	1979	1980	1981	1982	1983
Non-Catalyst	.102 1119	.085 1092	.046 1121	-	-	-
Oxidation Catalyst	.887 1687	.868 1627	.791 1401	.143 1154	.116 1090	.086 1117
Open loop 3-Way	.002 1446	.009 1286	.013 1124	.022 1315	.021 1266	.003 1247
Open loop 3-Way + Ox	- -	.000 1361	.004 1368	.115 1308	.166 1249	.106 1348
Feedback 3-Way	- -	.009 1419	.081 1491	.271 1371	.293 1364	.264 1326
Feedback 3-Way + Ox	- -	.007 1887	.020 1735	.395 1516	.328 1458	.457 1439

Source: Reference 5

3.15 Estimated Costs of Emission Controls to Meet Proposed Standards

While only a few manufacturers provided emission control hardware or system costs for their current systems, most manufacturers estimated the incremental costs for systems required to comply with the proposed standards. The manufacturer responses follow:

Chrysler Canada Ltd.

Chrysler estimated a $ 210 incremental retail price equivalent for upgrading their 2.2 litre engine family from an oxidation catalyst system to a three-way catalyst system. The details of the Chrysler estimate are shown in table 3-4. Chrysler noted that the estimated retail prices in the table do not include certification, research and development, or tooling costs to Chrysler. Inclusion of these items would result in a slight increase in the retail price. Chrysler selected the 2.2 litre engine family as an example of the retail price impacts they expect from the adoption of the proposed standards.

Ford Motor Company of Canada, Ltd.

Ford Motor Company estimated an incremental retail price equivalent of $175 in 1983 Canadian dollars. Ford did not furnish details on their estimate, but it represents the costs of upgrading their systems from essentially a non-electronic oxidation catalyst design to a electronic feed-back three-way plus oxidation catalyst design.

General Motors of Canada Ltd.

General Motors did not furnish any cost information "since we are still reviewing the costs of systems we anticipate could be offered in 1986 and subsequent model years and are not in a position to comment on costs at this time." They added, however, that "we have no objections to you using publicly available industry cost estimates since we expect to be competitive with others at the first cost to the consumer level."

Honda Canada Inc.

Honda estimated the retail price of the system they would use to meet the proposed standards as $795. Their system is comprised of the following: engine modifications ($45), pulsation air system ($65), air/fuel enleanment ($30), exhaust gas recirculation ($105), oxidation catalyst ($285), auto choke/deceleration device/piping ($55), evaporative emissions control ($35) and stratified charge engine ($185). Assuming a factor of 1.2 for dealer markup, the retail price equivalent would be $955. Comparing this estimate to the computations in section 2.54, the incremental price increase over a non-catalyst system is $480-$805, and $345-$545 over a similar oxidation system used to meet current standards.

TABLE 3-4

RETAIL PRICE COMPARISON OF ALTERNATIVE 1986 EMISSION CONTROL SYSTEMS FOR CANADIAN PASSENGER CARS

Feature	2.2L Engine 1986 Base System 2.0 HC, 25 CO, 3.1 NO_x	2.2L Engine 1986 New Proposal 0.4 HC, 7.0 CO, 1.0 NO_x	
Front Catalyst	45 (10-0)	105(10:1) + 45(0-20)	$ 75
Rear Catalyst	None	None	--
Thermal	Underbody and dash panel heatshields	Underbody and dash panel heatshields (extra shielding required)	10
Air Injection	One upstream aspirator	Air pump with switching	60
Spark Control	ESA	ESA	--
Carburetion	Standard	Feedback	65
Retail Price at 1983 Economics ($Canadian including 9% Federal sales tax)	Base Price	Base Price +	$210

*Catalyst volume given in cubic inches, with precious metal loadings in parentheses in units of mg/in^3. Numbers separated by a hyphen denote Pt-Pd content, a colon denotes Pt:Rh.

Source: Chrysler Canada Ltd.

Toyota Canada Inc.

Toyota provided very complete consumer cost data for emission control systems designed to meet both current and proposed emission standards. Table 3-5 presents Toyota's retail price data in 1983 Canadian dollars.

Table 3-5

Toyota Retail Price Estimates for Current and Proposed Standards

System	Retail Price to Meet Current Standards	Retail Price to Meet Proposed Standards
Sub-Compacts		
1. Non-catalyst (EM,AI,EGR,EVA)	$ 182	Not Applicable
2. Oxidation Catalyst (EM,AI,EGR,OC,EVA)	227	Not Applicable
3. 3-Way/Ox Catalyst, Feedback (EM,AI,EGR,FBC,TWO,EVA)		600
4. 3-Way Catalyst, Fuel Injection (EM,EFIM,TWC,CC,EVA)		860
5. 3-Way,EGR,Fuel Injection (EM,EGR,EFIM,TWC,CC,EVA)		702
6. 3-Way,EGR,Fuel Injection,HEI (EM,EGR,EFIM,TWC,CC,EVA,HEI)		1245
Compacts		
1. Three-way, Fuel Injection (EM,EGR,EFIM,TWC,CC,EVA)		753

Abbreviations:

EM = Engine Modifications
AI = Air Injection
TWO = 3-Way/Oxidation Catalyst
CC = Computer Control
EFIM = Electronic Fuel Injection (Multi-point)
EGR = Exhaust Gas Recirculation
HEI = High Energy Ignition
TWC = 3-Way Catalyst
FBC = Feedback Carburetor

Based on Toyota's data, there will be an incremental retail price increase of about $400 for those models which must be upgraded from either non-catalyst or oxidation catalyst systems.

Volkswagen Canada Inc.

Volkswagen commented that "for gasoline-fueled vehicles, the control technology required for Canadian-specific vehicles would have to be vastly modified to achieve 1.0 gram/mile NOx. To meet this standard in the United States, an expensive 3-way catalyst and closed-loop feedback control system was required. The cost difference between open-loop and closed-loop systems is approximately $125. Volkswagen's Canadian-specific vehicles do not require even the simpler catalyst system. Therefore, considerably more extensive modifications, at greater cost, would be necessary to bring Canadian vehicles into compliance with a 0.62g/km (1.0 g/mi) NOx standard. Thus, applying an exchange rate of $1.24 Canadian to $1 U.S. Volkswagen projects at least $155 to upgrade from an open-loop system to a closed-loop three way system.

Peugeot (represented by U.S. Technical Research Company)

Peugeot did not provide emission control system costs, but, they predict a six percent increase over the cost of a 1982 vehicle for upgrading to a closed-loop three-way system and an eleven percent increase for upgrading to an open-loop, multi-point injected, three-way system.

Renault USA, Inc.

Renault estimated that it would cost the consumer $650 (1983 Canadian dollars) to upgrade their mini-subcompact (less than 907 kg (2000 lb)) from a non-catalyst to a oxidation catalyst system and $940 to upgrade the balance of their models to a closed-loop three way catalyst system. According to Renault these increases represent 250% and 380% increases in emission control price, respectively, for the mini-subcompact and the balance of production.

Summary and Conclusions

Aside from the industry estimates above, the only other significant source of cost data was the U.S. EPA. The EPA estimation methodology and cost data are discussed in section 2.5. The EPA estimates in 1983 Canadian dollar are:

System	Retail Price Equivalent
Non-Catalyst	$ 130
Oxidation Catalyst	390
3-way, Feedback Fuel Injection	640
3-way, Feedback Carburetor	490
3-way, Open Loop Carburetor	420
3-way + Ox, Feedback Carburetor	630
3-way + Ox, Open Loop Carburetor	420

Table 3-6 is a summary and comparison of the manufacturer and EPA estimates of incremental increases in price to upgrade emission control systems from present systems to those needed to meet proposed standards. As expected, there is a range in reported prices which reflects differences in production volume, hardware sophistication, cost accounting, allocation practices, and other cost factors. The authors' best estimate of the incremental cost impact to the consumer of adopting the proposed standards is about $200 for upgrading the current oxidation catalyst system to a three-way and about $400 for upgrading the current non-catalyst system to a three-way system.

Table 3-6

SUMMARY AND COMPARISON
OF INCREMENTAL RETAIL PRICES TO MEET PROPOSED STANDARDS

(1983 Canadian Dollars)

Action/Source	Incremental Price Increase
From Non-Catalyst to Feedback 3-Way Catalyst	
EPA (carburetor)	$ 360
(single point injection)	510
Honda	480 - 805
Toyota (carburetor)	418
Renault	940
From Oxidation to Feedback 3-way Catalyst	
EPA (carburetor)	100
(single point injection)	250
Chrysler (carburetor)	210
Honda	345 - 545
Toyota (carburetor)	373
Volkswagen	greater than 155
From Oxidation to Feedback 3-way + Ox Catalyst	
EPA (carburetor)	240
Ford (carburetor)	175
Toyota (carburetor)	452

3.16 Disaggregated Retail Price Equivalent Estimates

The EPA retail price equivalent estimates for the emission control systems listed in the Summary and Conclusions of the previous section (3.15) can be disaggregated into their component parts using the Lindgren equation as modified to take into account the application of the Canadian federal sales tax.

The components of the retail price equivalents as a percentage of the total are shown in Table 3.7. The land and building expense (LBE) is not shown since Lindgren assumed that the components would be manufactured and assembled in existing facilities. Exclusion of the LBE may be debatable for the U.S., but certainly appears to be a justifiable assumption for the Canadian situation.

The estimates in Table 3.7 were derived by calculating values for each variable (price components) in the modified Lindgren equation for a number of pieces of emission control hardware and a representative catalyst. Since about one half of the retail price equivalent of a typical emission control system is accounted for by the catalyst and the other half by hardware, the values for the parts and the catalysts were weighted so that their respective retail price equivalents represented approximately one half of the entire emission control system. The values of the corresponding price components for the hardware and the catalyst were then added to get price components for a typical emission control system. This approach was used to ensure that differences between the price structure of catalysts and hardware were properly reflected. An example of such a difference is that the cost of materials as a percentage of plant manufacturing cost for catalyst is considerably higher than for pieces of emission control hardware.

The final step in the calculation was to convert the value of each price component of the modified Lindgren equation into a percentage of the system retail price equivalent.

The retail price equivalent using Lindgren's equation can be approximated as:

$$RPE = (M \times Ct) + Ci$$

where

RPE = retail price equivalent.

M = markup factor that accounts for parts manufacturer, vehicle assembler and dealer markups, and the federal sales tax.

Ct = total plant manufacturing cost.

Ci = capital investment, including R&D, a portion of tooling costs, and investment.

Using Lindgren's markups, the markup factor works out to be 2.7. However, as part of EPA's analysis of the 1984 light-duty HC and CO truck standards, EPA analysts reviewed Lindgren's markup factor and concluded that 1.81 (1.93 with the federal sales tax added) more accurately reflects actual parts manufacturer, vehicle assembler, and dealer markups (reference 2).

For this reason, disaggregated retail price equivalents are shown in Table 3.7 for markup factors of 2.7 and 1.93.

Table 3-7

PRICE COMPONENTS AS A PERCENTAGE OF

RETAIL PRICE EQUIVALENTS

Component	Markup Factor	
	2.7	1.93
Plant manufacturing cost		
material	22.9 %	31.4 %
labour	7.0	9.6
plant overhead	2.8	3.8
Subtotal	32.7	44.8
Component vendor markup	13.1	10.3
Tooling expense	2.8	2.9
Assembly, engine and body modifications	1.4	2.0
Total -- Vehicle assembler cost	50.0	60.0
Vehicle assembler cost	50.0	60.0
Vehicle assembler markup	19.8	13.8
Federal sales tax	6.3	6.6
Dealer markup	19.8	13.8
Research and development	4.1	5.7
Total -- Retail Price Equivalent	100.0 %	100.0 %

Note: Numbers may not add to exactly 100.0% due to rounding.

Source: Authors' estimates as explained in the text.

3.17 Fuel Consumption Impacts

The manufacturers uniformly estimate a fuel consumption penalty for their passenger car fleets if the proposed standards are adopted. Generally, this estimate is based on comparisons of vehicles with unique canadian emission control calibrations against similar vehicles employing U.S. federal emission control systems. The main technical explanation given by the manufacturers for the poorer performance of the U.S. federal systems, more specifically the three-way catalyst system, is that the air/fuel ratios of these systems must be calibrated at or slightly rich of the stoichiometric point, whereas, the optimum calibration for minimum brake specific fuel consumption is lean of the stoichiometric point. While this argument is technically correct, air/fuel ratio is only one of many emission control system and powertrain design and operating parameters that can effect fuel consumption. These considerations will be discussed subsequently. The individual manufacturer estimates of fuel consumption impacts are:

Chrysler Canada Ltd.

The Chrysler position on fuel consumption impact is "that a fuel economy loss is incurred with increased NOx control. We estimate this loss would amount to about a 2% penalty for either a 1.0 or 2.0 gram per mile standard, compared to the present 3.1 level. Nevertheless, due to present market positions and long-range energy supply considerations, automobile manufacturers must strive to maintain high fuel economy at all reasonable costs, regardless of the stringency of NOx standards. If NOx standards must be tightened, Chrysler will take sufficient engineering measures to ensure that its motor vehicles remain competitive on a fuel economy basis". (Note: Because of the differing mathematical bases for fuel economy and fuel consumption, fuel consumption percentage change is slightly higher than fuel economy percentage change for the same effect.).

Ford Motor Company of Canada, Ltd.

Ford compared the fuel economy of 1980 model year U.S. 49-state federal vehicles against the fuel economy of California versions of the same models. In this case the NOx standard was 2.0 g/mile for the federal cars and 1.0 g/mile for the California cars. Ford reported that "for Ford engine families with comparable emission control systems and comparable catalyst, the fuel economy penalty for vehicles calibrated to meet California's 1.0 was from 3 to 6%." Ford translated these data into a 0.3L/100km (metro-highway) loss for the average Ford vehicle if the Canadian standards are changed from the current to proposed values.

General Motors of Canada Ltd.

General Motors provided the data exhibited in table 3-8 which compares the fuel consumption characteristics of their 1982 models sold in the U.S. and Canada. The recalibrated models offered in Canada (oxidation catalyst systems) are compared against the U.S. federal models (closed-loop, 3-way catalyst systems). The results show a wide range of fuel consumption differences for the different classes of vehicle for both city and combined driving cycles. In general, the Canadian models show lower fuel consumption.

Table 3-8

GENERAL MOTORS 1982 MY FUEL CONSUMPTION COMPARISONS

City Fuel Consumption (L/100 km)

Class	Canadian			U.S Federal		
	Min.	Max.	Avg.	Min.	Max.	Avg.
Sub-compact	7.5	14.0	9.3	10.2	14.7	14.5
Compact	8.0	10.8	9.7	9.3	10.7	10.5
Mid-size	8.5	12.5	11.2	9.6	15.0	14.1
Full-size	12.1	14.3	13.6	13.4	22.8	13.8
Small Wagon	9.0	9.3	9.2	9.3	9.3	9.3
Mid-size Wagon	11.4	13.0	12.2	12.4	14.1	13.1
Large Wagon	13.5	14.4	14.2	14.8	16.1	15.4
Combined City/Hwy Fuel Consumption						
Sub-compact			8.0			12.3
Compact			8.0			8.6
Mid-size			9.5			11.6
Full-size			11.5			11.8
Small Wagon			7.6			7.7
Mid-size Wagon			10.4			11.3
Large Wagon			12.2			12.9

Source: General Motors Questionnaire Response

Honda Canada Inc.

Honda estimates that their vehicles would incur a fuel consumption penalty of around 5% (response to Canadian Gazette Notice) to 10% (response to questionnaire) if the proposed standards were adopted.

Toyota Canada Inc

Toyota estimates that the fuel consumption impact on their models from adoption of the proposed standards would range from an increase of 3% to a decrease of 3%.

Volkswagen Canada Inc.

Volkswagen reported that "electronic control hardware installation results in fuel consumption decreases. As compared to U.S. versions using such hardware additional reductions in fuel consumption result from innovative drivetrain technology and driver education (e.g. shift indicator lights)."

Peugeot (represented by U.S. Technical Research Company)

Peugeot provided a fuel consumption comparison for one of their 1982 engine families between the Canadian and U.S. federal versions:

	Fuel Consumption (L/100 km)			
	Canadian XNA Engine Family		United States XN6 Engine Family	
	City	Hwy.	City	Hwy.
Automatic Trans.	12.3	8.4	10.7	7.4
Manual Trans.	12.7	9.4	11.2	9.4

Based on this example, Peugeot estimates a 12% fuel consumption improvement for 1982 Canadian vehicles equipped with manual transmissions and a 6% fuel consumption improvement for 1982 Canadian vehicles if the emission control systems are upgraded to U.S. versions.

Renault USA, Inc.

Renault predicts an 8% increase in fuel consumption for their mini-sub-compact model which would be upgraded to an oxidation catalyst system and a 5% increase in fuel consumption for the balance of their models which would be upgraded to closed-loop, three-way catalyst systems.

Regulatory Agencies

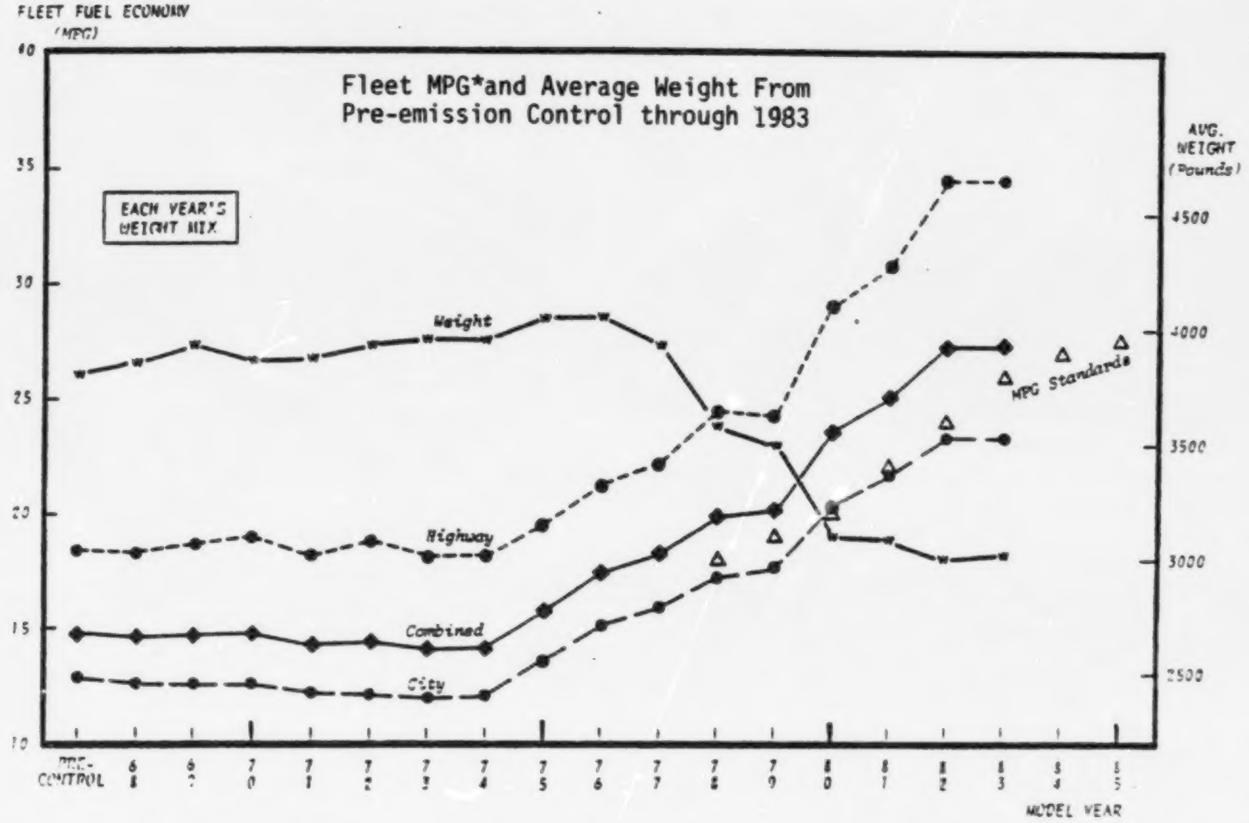
The regulatory agencies in Canada and the United States have extensively studied the relationship between fuel consumption and emissions control. In general, they have shown that fuel consumption (or economy) has steadily improved each year, both during years that emission standards took effect and in years that emission standards remained unchanged. They have concluded that there is no inherent relationship between emission standards and fuel consumption that states that fuel consumption must increase as emission standards are made more stringent or vice versa. Instead, they have found that at any given emission control level the fuel consumption characteristics are a strong function of the emission control technologies used. When the fuel consumption characteristics of the most sophisticated emission controls at each emission control level are compared there are no significant fuel consumption differences between different levels of emission control.

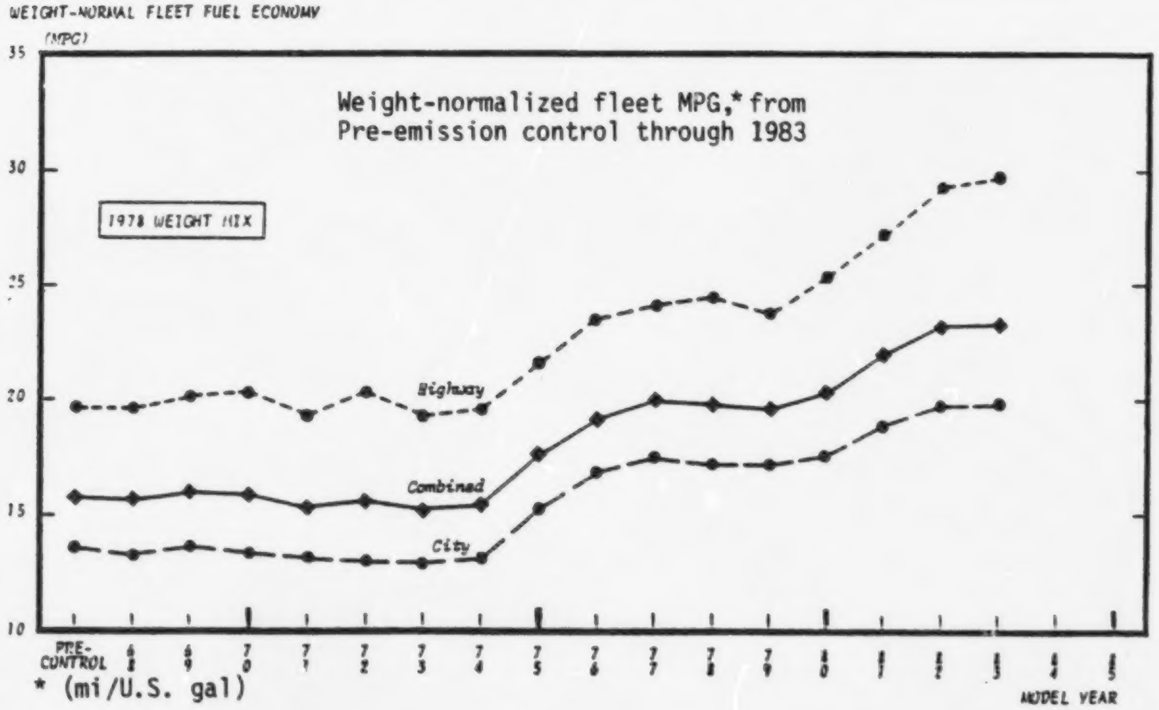
Comparisons between California and U.S. federal calibrations have often shown poorer fuel economy for the California cars. However, EPA notes that the California emission standards have always preceded the federal standards in stringency, so that the comparisons are usually made between new technologies in their first or second year of application and mature technologies. Also, EPA notes that, the smaller size of the California market may not justify the expenditure of the resources needed to fully optimize emission control designs for fuel consumption.

Government comparative studies between Canadian and Federal Specification Cars have found little significant difference in fuel consumption between the vehicles, especially when a broader temperature range was studied and when road fuel consumption measurement procedures were employed. (references 12,13).

The U.S. EPA evaluates, on an on-going basis, the fuel economy characteristics of U.S. federal emission control vehicles using the extensive certification data base. The results are published annually at the national meeting of the Society of Automotive Engineers (SAE) (reference 5). This year's paper, the eleventh edition, concludes that one of the factors affecting the steadily improving trend in weight-normalized fuel economy shown in figure 3-7 is emission control. The bottom graph of figure 3-7 shows fleet fuel economy after the effect of vehicle weight is removed from the fuel economy figures (i.e. the data are weight normalized). The data in table 3-9, taken from the EPA paper, shows that, since 1975, weight-normalized fuel economy has improved much more in the years when emission standards were tightened, than in years when they were unchanged. EPA credits emission control standards (by forcing engine/drivetrain changes) with 6.4 % fuel economy improvement for the HC standards, 5.1 % improvement for the CO standards, and 1.8% for the NOx standards.

FIGURE 3-7





* (mi/U.S. gal)

Source: Reference 5

Table 3-9

AVERAGE CHANGES IN WEIGHT-NORMALIZED FUEL ECONOMY VS. EMISSION STANDARDS

Standard	Pre-1975		1975 & Later	
	When Stds. changed	When they did not	When Stds. changed	When they did not
HC	-0.2%	+0.3%	+8.7%	+2.3%
CO	-0.2%	+0.3%	+7.4%	+2.3%
NOx	-2.2%	+0.3%	+4.1%	+2.3%

Source: Reference 5

Analysis and Conclusions

The answer to the question "What is the fuel consumption impact of the proposed emissions standards?" is difficult and speculative.

From a purely technical consideration, there should be no significant difference in fuel consumption between unique Canadian calibrations, currently sold, and those calibrations required for compliance with the proposed standards. The current Canadian emission control systems are largely open loop, non-electronic systems, with many already employing catalytic control. The U.S.federal systems, which will be the precursors of the systems needed to meet the proposed standards, are closed-loop, electronic controlled systems. Any fuel consumption difference caused by the richer air/fuel ratio of the U.S. federal system is easily offset by the benefits of electronic control and, if necessary, by downsizing engine displacement (operation at the richer air/fuel ratios of the federal system increases engine power). Further, greater application of fast burn techniques and expansion of electronic control to additional engine systems (e.g. electronic control of air, spark, and EGR, and improved fuel injection systems) will cause continued improvement in federal systems.

However, the manufacturers are quite correct in emphasing the necessity to make trade-offs between emissions, fuel consumption, cost, driveability, and other performance parameters. In turn, this trade-off is affected by conditions that are often outside of the control of the manufacturer, such as, the health of the automotive market and the general economy, and the time and resources available to the manufacturer. At current emission control levels, most manufacturers possess a large baseline of certified designs from prior U.S. experience from which to select and optimize fuel economy without much expenditure. At proposed levels, most, if not all, manufacturers will have to use the U.S. emission controls systems in effect at the time the proposed levels are adopted. The Canadian market, according to the manufacturers, is simply too small to justify a separate Canadian calibration. Thus, the tradeoffs will be dictated mainly by market and economic trends in the U.S. If the U.S. buyer continues to place emphasis on fuel economy, then fuel consumption of Canadian vehicles meeting the proposed standards should be equal to or better than current Canadian offerings.

All factors considered, it is the judgement of the authors that the fuel consumption impact of adopting the proposed standards will be minimal and slightly positive --- a fuel consumption improvement of 1 to 2 percent. This is based on the author's judgement that expanded use and improvement of electronics, fuel metering systems, and fast burn techniques will bring about a 5-6% improvement in U.S. federal systems by MY 1986 which will offset any fuel consumption increases due to the richer air/fuel calibrations of the three-way systems.

3.18 Durability, Maintenance, Driveability and Other Impacts

The manufacturers responding to the survey questionnaire uniformly reported that they do not expect any impacts on durability, maintenance, or driveability as a result of the proposed standards. For example, General Motors responded "we do not anticipate any problems obtaining satisfactory driveability and durability with any emission control systems we are considering for the proposed emission standards. We would compromise fuel efficiency to the extent necessary to meet the applicable emission standards and obtain satisfactory driveability."

We agree with the manufacturers' comments. In fact, the proposed standards will require increased use of unleaded fuels and stainless steel components so that exhaust system durability will be enhanced. Since these systems will be calibrated richer and employ advanced electronic controls, driveability should also be enhanced -- including cold weather starting and performance.

The only durability concern is the inadvertent or purposeful use of leaded fuels in vehicles with oxygen sensors. The sensors (and the catalysts) are poisoned by sustained usage of leaded fuels. Failure of the sensor as a result could lead to excessively rich operation with resultant increases in CO and HC emissions and fuel consumption.

3.19 Lead-time Considerations

The manufacturers were uniform in reporting on their lead-time requirements. If a U.S. emission control system is available and will not require much change, then 12 to 18 months is adequate lead-time. If the system requires additional redesign and certification testing then 36 months lead-time is more appropriate. Table 3-10, submitted by General Motors, is typical of the longer lead-time schedule.

We conclude that a 30 month lead-time schedule would be appropriate because it allows manufacturers to recalibrate U.S. federal systems and take advantage of the more lenient CO standard compared to U.S. standards. This allows trade-offs for lower cost (e.g. elimination of add-on oxidation catalysts) and better fuel consumption (by taking advantage of electronic improvements).

3.110 Evaporative Emissions Standards

The scope of work for the study also required examination of the feasibility of adopting a 2 gram SHED evaporative standard. None of the manufacturers responding to the survey questionnaire reported any concern or difficulty in achieving a 2 gram SHED evaporative standard. This is not surprising since most manufacturers use the U.S evaporative control design which already meets this standard. In a few instances, some models may have to be upgraded. For example, Toyota reported that most of their light duty vehicles already comply, but their 1.5 and 1.6 litre engine families would require modifications costing $ 23 additional.

3.2 Passenger Diesel-Engined Vehicles

3.21 Technical Feasibility

The technical feasibility of meeting proposed standards with diesel-engined passenger vehicles is vigorously challenged by the industry. It is generally agreed that the diesel engine equipped vehicle cannot meet NOx standards below 0.93 - 1.24 grams per kilometre (1.5 - 2.0 g/mile) without the use of add-on emission control devices. Equally important, as NOx is controlled below these levels, many NOx control measures, that are effective at these levels, cause increases in particulate emissions as the NOx emissions are reduced.

Mercedes-Benz, with approximately seventy-seven percent of Canadian sales being equipped with diesel engines, provided extensive comments on the NOx issue. They reported that "presently Daimler-Benz knows of no technology ready for production which would achieve a 1.0 gram/mile NOx standard in its light-duty diesel vehicles."

The major thrust in NOx controls has been and continues to be the employment of exhaust gas recirculation (EGR). Daimler-Benz reports that the use of mechanically-controlled EGR systems has allowed it to certify passenger cars in the 1.25-1.5 g/mile NOx range. When this system was introduced in 1980, Daimler-Benz believed that, with continued development, the mechanical EGR system could eventually achieve 1.0 g/mi NOx. However, now they believe that mechanical control systems for EGR do not adequately modulate EGR flow rates at the 1.0 g/mile level. Consequently, Daimler-Benz has applied for NOx waivers in the United States, for both federal and California standards.

The main problem with the current EGR systems is control accuracy -- the ability to apply the right amount of EGR as a function of engine load. At light engine loads there is sufficient excess air to permit large EGR rates without adverse effects on engine performance. However, at heavy and full load conditions, when EGR control is most needed, the tolerance of the engine to EGR flow rate is most critical. If excessive EGR is applied at these conditions, the engine may knock or stall and increases in gaseous and particulate emissions and fuel consumption are obtained. Further, in turbo-charged engines EGR rate control is critical under certain transient conditions of engine operation.

At the present time, the control signal for modulating EGR rate with engine load and speed is taken from the injection pump governor control. Because of mechanical tolerance limitations on this system, conditions of EGR flow "mismatch" can occur, leading to the problems discussed above. In addition, the normal variations in cylinder-to-cylinder injection amounts that are caused by mechanical tolerance variations in the fuel injection system can lead to EGR flow "mismatch" in some of the cylinders. As a result most manufacturers of diesel engines are working on ways to reduce these tolerance variations. Daimler-Benz reported that its "development work has shown that tolerances cannot be restricted enough to permit certification and field operations of vehicles reliably below the standard of 1.5 g/mi."

Another limitation on the mechanically-controlled EGR is that response times are not fast enough for the precise control needed at high engine speeds and transient operation.

The need for better optimization of EGR flow rates has prompted most engine manufacturers to explore the application of electronic EGR controls. In this approach, extensive maps are taken of the engine to link engine parameters, such as, load and speed, to required EGR rates. The acquired data are then stored in the memory sections of a micro-processor. During engine operation, the engine parameters are measured by appropriate sensors and control signals are transmitted to the micro-processor. The micro-processor interprets the signals and computes an appropriate EGR flow rate, which is then used to control the EGR system.

Most manufacturers have expressed guarded optimism for the capability of the electronic EGR system to achieve 1.0 g/mile NOx levels. As with the mechanical EGR system, there is still some difficulty in obtaining adequate response times, even with the electronic system.

Even if successful EGR systems are developed, many manufacturers will object to the use of EGR because of fears that particulates, recirculated along with exhaust gas, will cause durability problems. The concern is that recirculated particulate will cause premature wear of piston rings, cylinder walls or liners, and valves. Many believe that more frequent oil changes and EGR filters will be necessary.

Other NOx control techniques may be applied to the engine, but, these techniques are insufficient to control NOx below 1.5 grams/mile by themselves. The techniques include application of turbo-chargers and intercoolers, better divided chamber designs, injection timing retard, better swirl designs, higher pressure fuel injection pumps, better speed/load injection timing control, electronic fuel injection control, and optimized valve timing.

Particulate Control

The question of technical feasibility for NOx control cannot be addressed without consideration of particulate control requirements. As already mentioned, there is a complex trade-off between the gaseous and particulate emissions and fuel consumption. Table 3-11 illustrates this trade-off.

The U.S. Environmental Protection Agency has promulgated a 0.6 g/mile particulate standard for 1982 and later model year diesel-powered passenger cars and a 0.2 gram/mile particulate standard for 1985 and subsequent model year vehicles. The rule was challenged by the industry but the rule was upheld by the court. EPA has proposed that the 0.2 g/mi standard be delayed two years to be effective with the 1987 model year. This delay is expected to be promulgated as a final rule very shortly.

At a 0.6 gram/mile particulate standard, NOx can be effectively controlled with mechanically controlled EGR down to levels of 1.25 - 1.5 grams/mile. Electronically controlled EGR systems under development show considerable promise for reducing this NOx to 1.0 g/mile. While EGR controls can increase particulate, other techniques, shown in table 3-11, can be used to mitigate this increase.

Table 3-11

The Interactions of Diesel Emission Control Technologies

Technology	Effects On			
	HC	NOx	Particulate	BSFC*
Exhaust Gas Recirculation	down	down	up	up
Cool Inlet Air	up	down	--	down
Early Timing of Injection	down	up	down	down
Min. Dead Volume	--	--	down	--
Low Sac Nozzle	down	--	up	--
Low Swirl	down	up	up	down
High Compression Ratio	down	--	up	--
Injection Pressure	--	down	down	--
Pre-Chamber Orifice (larger)	--	down	up	--
Speed Variable Timing	down	up	down	down
Load Variable (Advancing Timing)	--	up	down	down
Load Variable (Retarding Timing)	--	down	up	up
Turbocharger	down	down	down	--
Water Injection	--	down	--	--

Note: -- implies mixed or neutral response to control technique. Not all engine designs will behave exactly the same to each technique, so that there may be mixed responses by some engines even if up or down shown.

* Brake Specific Fuel Consumption

Source: Authors Assessment

However, if a 0.2 gram/mile particulate standard is established along with a 1.0 gram/mile NOx standard it is questionable whether the particulate standard can be met without some form of aftertreatment of the exhaust. The after-treatment devices are essentially filters that are combined with a technique to regenerate the filter or remove the trapped particles. Corning Glass Works has developed a very effective ceramic particulate trap that is essentially their automotive honeycomb catalyst substrate with every other flow channel blocked at either end. These designs have demonstrated the capability of removing enough particulate to meet the lowest proposed U.S. federal particulate standard and have exhibited beneficial reductions in odour and smoke, as well. The main problem is that exhaust temperature of a diesel engine, except when under heavy load, is too low to "burn-off the trapped particles". Periodic cleaning of the trap, under a preventative maintenance program, is infeasible because of the low mileage intervals that would be required. Various techniques to increase exhaust temperatures, such as, afterburners, external heating, and engine throttling under load conditions have only been partially successful, probably, because the trapped particles have sintered and partially plugged the filter.

The most promising regeneration techniques involve the application of catalysis. In the case of the Corning trap, it was discovered that when smoke suppressant fuel additives such as manganese compounds were used in conjunction with the trap, the problems of regeneration were largely allievated. It is believed that the heavy metals from the additive provide active catalyst sites on the filter which result in burning of the particulate. However the health, environmental and economic issues connected with the wide-scale use of these fuel additives remains to be evaluated.

Johnson Matthey has taken a more classical approach and has applied noble metal catalyst coatings to their trap which consists of steel mesh as the filter medium. The results on experimental vehicles have been very encouraging. The main questions surround issues of cost and trap durability.

3.22 Comments by Manufacturers on Technical Feasibility

Comments by the industry on the technical feasibility of meeting proposed standards with diesel-engined passenger cars were limited because of the relatively small sales of this class of vehicle in Canada. The following manufacturer comments were received:

BMW AG

BMW noted that "For diesel-engined vehicles, however, the 0.62 g/km (1.0 g/mi) NOx standard should not be implemented with the 0.37 g/km (0.6 g/mi) particulate standard. For diesel vehicles a NOx standard of 1.24 g/km (2.0 g/mi) would be appropriate."

General Motors of Canada Limited

General Motors emphasized that the level of NOx emissions from diesel engines is strongly dependent on engine size and that all uncontrolled diesels, irrespective of size, emit NOx at levels greater than 1.0 g/mi. GM believes that the most effective method of controlling NOx emissions from diesels is through the use of EGR. Like other manufacturers, GM reports problems with EGR including increased particulate, contamination of oil with particulate, and increased engine wear. GM concludes that "the seriousness of these effects varies with the stringency of the NOx standard, but, at a 1.0 g/mile NOx level, the required amounts of EGR would be excessive -- enough to preclude further production of all but perhaps the very smallest car diesel engines."

Mercedes-Benz of North America, Inc.

Mercedes-Benz reported that "Daimler-Benz was able to achieve acceptable results for model years 1980-1982 with its limited EGR system designed to meet a 1.5 gram/mile standard, but has to date been unable to achieve this goal with the same system in order to reach 1.0 gram/mile NOx." To meet the more stringent standard, Mercedes-Benz is concentrating it's efforts on developing an electronic EGR system. Mercedes-Benz reports that this system "has only been developed for a naturally-aspirated 3.0 litres engine. Daimler-Benz has also begun the initial steps to adopt this system to our turbocharged diesel engine. The main development target here is to find a basic logic incorporating and adjusting for the characteristics of a turbocharged diesel engine. This will require microprocessing solutions to overcome problems during transient engine operation caused by the turbocharger unit, and those caused by interference between the EGR system and the sensitive pressure build-up by the turbocharger. Daimler-Benz cannot predict whether the foregoing technological problems can be resolved by model year 1985."

Based on its technical problems with the development of an electronic EGR, Mercedes-Benz "opposes a requirement that light-duty diesel vehicles meet a 1.0 gram/mile NOx standard ..... In its stead, Daimler-Benz supports a standard of 2.0 g/mile NOx, which would eliminate the need for exhaust gas recirculation."

Nissan Motor Company, Ltd.

Nissan reported that "for models equipped with diesel engines, we have been trying to meet a 1.0 gram/mile (0.62 gram per kilometre) standard by using an exhaust gas recirculation (EGR) system. However, we are not yet able to meet this NOx standard because of increases of hydrocarbon (HC) and particulate emissions, diesel smoke, and wear of engine components due to the EGR system."

Peugeot

Peugeot reported that EGR was the only system currently available to meet the proposed standards. Peugeot has used a mechanically-controlled EGR system in the United States to achieve a NOx level of 1.5 g/mile, but, reports that the system cannot achieve a production NOx level of 1.0 g/mile. To achieve lower NOx levels, Peugeot believes it must add electronic control to the EGR system and is currently pursuing such development. Current problems encountered in the development of this system, because of the increased EGR rates, include: clogging of inlet tracts and valves with carbon, degradation of the lubricating oil by carbon particulate, increase HC and particulate emissions, and increased fuel consumption. Figures 3-8, 3-9, and 3-10 were provided by Peugeot to illustrate their electronically-controlled EGR, the effects of vehicle inertial weight on particulate and NOx emissions, and the effects of EGR on particulate and NOx emissions, respectively. Figure 3-9 shows NOx emissions increasing linearly with inertia weights for both normally-aspirated and turbocharged engines. Particulates also increase linearly with inertia weight for the normally-aspirated engine, but are lower and do not appear to be related to inertia weight for the turbocharged engine. Figure 3-10 illustrates the difficulty of simultaneously meeting both the NOx and particulate emissions objectives.

Renault USA, Inc.

Renault reports "Our tests are still insufficient for determining if an EGR system would be required to meet the standards proposed."

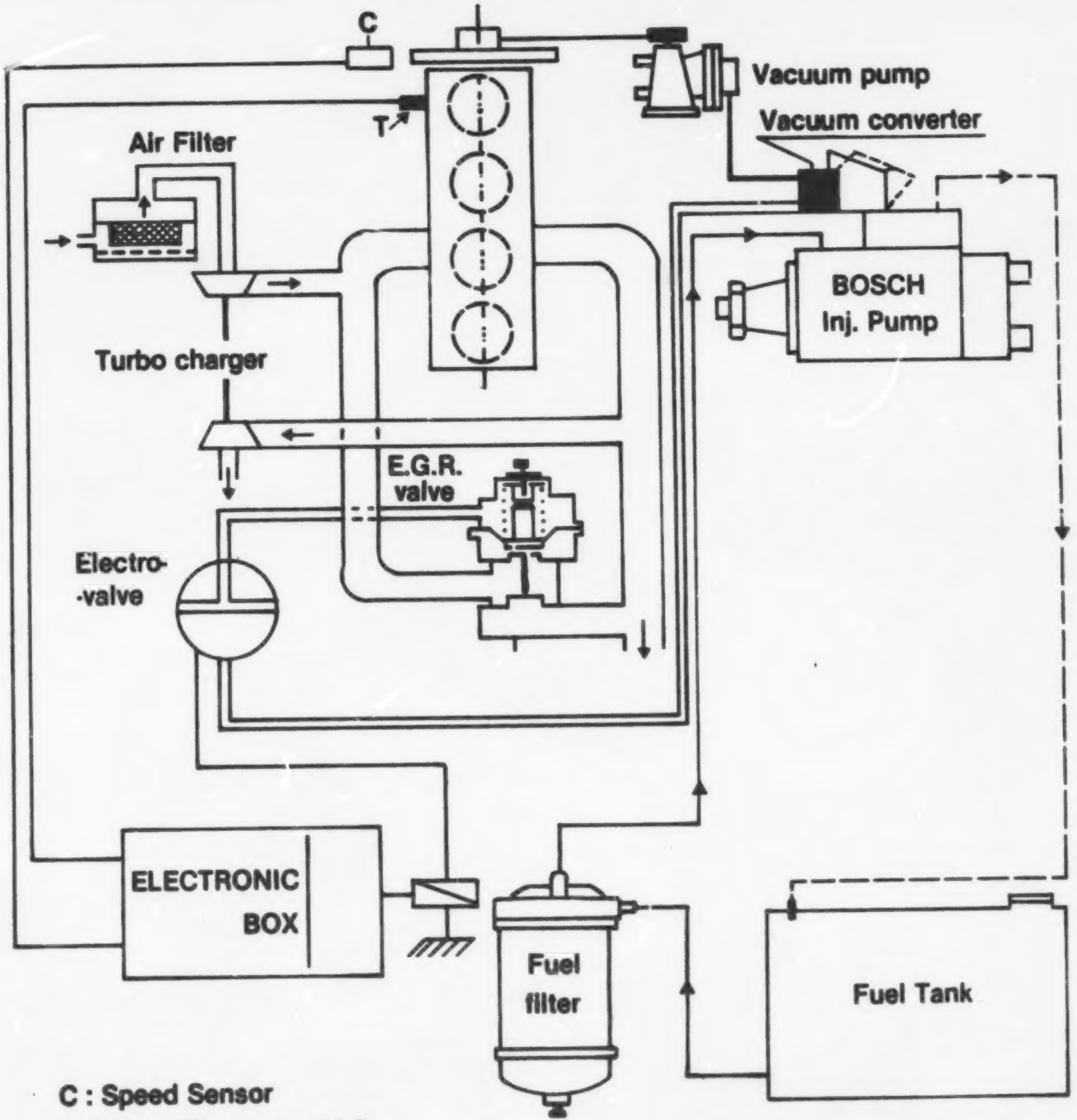
Volkswagen Canada Inc

Volkswagen summarized its position by providing this excerpt from a submission to the U.S. EPA: "NOx research for diesel vehicles has centered around trying to meet the 1.0 g/mile NOx standard contained in the Clean Air Act. Development has improved NOx levels to reach toward the 1.0 g/mile standard. While it has been possible to meet such a standard under certain conditions with specific vehicles, VW maintains that it is not technologically feasible to meet such a standard on a production basis."

Like many other manufacturers, VW obtained waivers from EPA for 1.3 g/mi for the smaller, light-weight vehicles, 1.4 g/mi for the intermediates, and 1.5 g/mi for the large, heavy vehicles. VW research is also focused on the development of EGR for further NOx reductions. VW also reiterated the problems with EGR as already discussed. VW concludes that "the requirement that motor vehicles meet a 1.0 g/mile NOx standard may preclude the sale of some models of the diesel-fueled vehicles."

FIGURE 3—8

EXHAUST GAS RECIRCULATION SYSTEM


C
T
Vacuum pump
Vacuum converter
Air Filter
Turbo charger
BOSCH
Inj. Pump
E.G.R.
valve
Electro-
-valve
ELECTRONIC
BOX
Fuel
filter
Fuel Tank

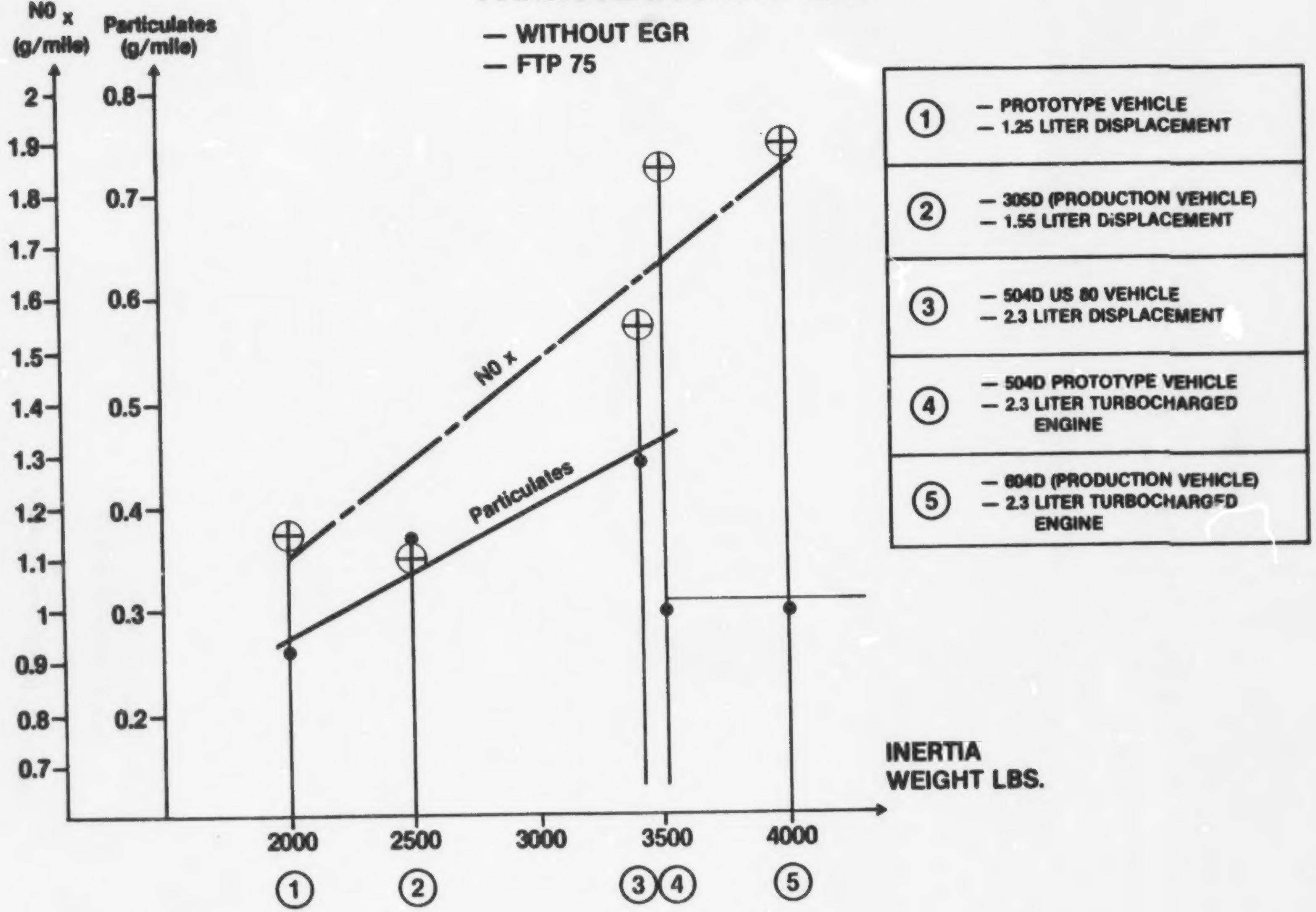
C : Speed Sensor
T : Water Thermocontact

Source: Automobiles Peugeot

FIGURE 3—9

EFFECTS OF THE INERTIA WEIGHTS ON PARTICULATES AND N0 x

— WITHOUT EGR
— FTP 75

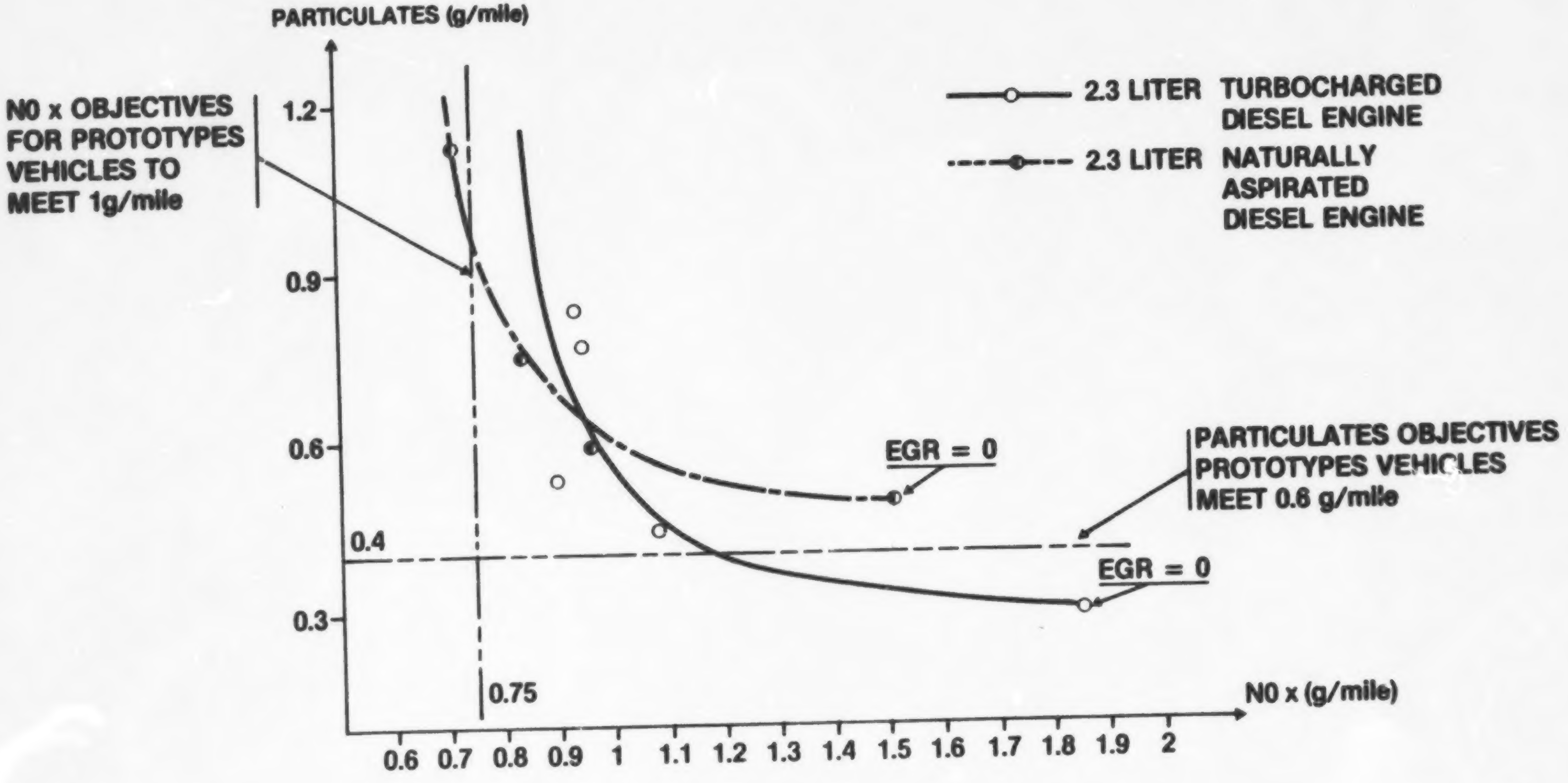


Source: Automobiles Peugeot

FIGURE 3—10

EFFECT OF EGR ON PARTICULATES — N0 x BALANCE

— 3500 lbs. INERTIA WEIGHT VEHICLE
— FTP 75



Source: Automobiles Peugeot

3.23 Costs of Emission Controls for Diesel-Engined Passenger Cars

Little or no emission control hardware is required for diesel-engined passenger cars at the current emissions standards. Very little cost data were provided by the manufacturers or reported in the literature. Further, it is difficult to estimate these costs because the EGR systems are still under development and production volumes for diesel equipped passenger cars are extremely small. However, for the sake of comparison, the costs discussed in the following two paragraphs can be considered costs at the retail level in 1983 Canadian dollars.

Volkswagen estimated retail costs in the range of $ 350-500 with the range representing the range between mechanically-controlled and electronically-controlled EGR systems. VW qualified their estimate with the cautionary note that these are merely estimates since no production systems exist. Renault estimates a cost of $260 for EGR, probably, mechanically-controlled.

Based on comparison to similar electronic control projects for gasoline-engines and low production volume of diesels, a projection of $ 300-500 is a reasonable cost estimate for an electronic EGR. A particulate trap, if required, would cost $ 150-250 depending upon type and production volume. Additional modifications to the engine, for HC and particulate may also be required, but these should cost no more than $ 100-150. In the worst case scenario, the emission control system would cost $ 900 at the retail level.

3.24 Impacts on Fuel Consumption, Maintenance, and Durability

Every manufacturer indicated that the EGR control system required to meet the proposed standards would increase the maintenance requirements for oil change and affect engine durability because of wear on engine components from particulate. However, the actual effect on durability was not quantified.

In terms of fuel consumption, most manufacturers indicated that EGR systems would increase fuel consumption, perhaps, up to 5%.

3.25 Summary and Conclusions for Diesel-Engined Passenger Cars

The technical feasibility for diesel-engined passenger cars meeting the proposed standards depends on whether a particulate standard is established for this class of vehicle,the engine size/vehicle weight combination, and the lead-time available.

Without particulate standards, all diesel engines with the exception of the large displacement engines (greater than 3 litres) in vehicles over 1360 kg (3000 lb), not incorporating divided chambers, are capable of meeting the proposed NOx standard of 0.62 g/km. The lighter vehicles could use mechanically-controlled EGR systems while the heaviest vehicles would have to use electronically-controlled EGR systems. Lead-times of 3 to 5 years would be required, depending upon whether electronic EGR systems would have to be employed (longer time for electronic EGR development).

If a particulate standard of 0.37 g/km were adopted along with the proposed NOx standard, most diesel engines could still comply but longer lead-times would be necessary to develop the electronic EGR systems and particulate control techniques. It may be necessary for the largest engines to incorporate add-on particulate traps. A 5 year lead-time would be necessary.

If a particulate standard of 0.12 g/km (0.2 g/mile) were adopted along with the proposed NOx standard, it is likely that all diesel engines, with the exception of the small displacement 4 cylinder engines, would require some form of add-on particulate trap.A minimum lead-time of 5-7 years would be required.

The above comments apply only to the question of technical feasibility. Whether or not the manufacturers would develop models to meet the proposed standards is another question. Most manufacturers have commented that the Canadian automotive market is small and does not justify large expenditures of time and resources for unique Canadian calibrations. Therefore, if the proposed standards were adopted, the availability of diesel-engined models would depend to a large measure on market considerations and the levels of U.S and California standards. For example, GM recently announced that the large diesel-engined models would not be available in California because the size of the market did not justify development of the required emission controls. At the present time, the market for diesel-powered vehicles is very small in Canada (less than 5% of sales).

3.3 Light-Duty Trucks

3.31 Technical Feasibility

The current standards for light-duty trucks are identical to those for passenger vehicles. For this study, the proposed standards for light-duty trucks are those that are currently in effect in the United States or 1.05 HC, 11.16 CO, 1.43 NOx grams per kilometre (1.7 HC, 18 CO, 2.3 NOx grams per mile). Many manufacturers in their responses to the Canada Gazette Notice addressed more stringent standards -- the standards being proposed for passenger vehicles -- for light-duty trucks.

The principal difference between light-duty trucks and passenger vehicles is that light-duty trucks are designed and used to carry significant cargo loads as well as passengers. In addition, the road load horsepower setting during the test is usually higher for trucks than equivalent size and weight passenger cars. Finally, the power train and transmission combinations are selected to match the higher load requirements of truck duty cycles.

To meet the growing demand for better fuel consumption and the increased use of light-duty trucks for personal use (as opposed to commercial and cargo hauling), light-duty trucks are offered in two distinct size categories. The mini-trucks are the equivalent of the passenger car sub-compacts and compacts and they often share the same basic powertrains. The other category, full-size trucks, represent the traditional light-duty truck offering and have large engines, heavy duty transmissions and suspensions, and often do not share any powertrains with passenger car equivalents.

Despite these differences, the identical emission control technology employed by passenger cars is applicable to light-duty trucks. In the case of the 1.05 HC, 11.16 CO, 1.43 NOx grams per kilometre (1.7 HC, 18 CO, 2.3 NOx g/mi) standards, the most stringent emission control system that would have to be used on gasoline-engined vehicles is the oxidation catalyst system. In fact, many Canadian light-duty truck models already employ the U.S. federal oxidation catalyst system. No controls would be required in the case of the diesel-engined vehicle because the uncontrolled diesel engine is capable of meeting the standard. Thus, at this level of emission control stringency, there is no issue of technical feasibility.

If the proposed passenger car standards were adopted for light-duty trucks there would be some questions of technical feasibility, at least for the diesel-engined light-duty truck. All gasoline-engined light-duty trucks would be capable of meeting the standard, but, the full-size trucks would have to use the most sophisticated closed-loop, three-way catalyst systems. However, since this standard would be more stringent than the U.S. federal standard, it is doubtful whether many manufacturers could afford to develop Canadian calibrations for the small production volumes in Canada. As an alternate, they would probably consolidate their offerings by dropping low sales models and consider recalibrating California models. There would be real questions whether diesel-engined light-duty trucks could meet this standard. The problems have been discussed in the passenger car section. In any event, given the even lower sales of diesel-engined light-duty trucks, the only option a manufacturer might have at this emission control level is to drop diesel engine versions.

3.32 Manufacturer Comments on Proposed Light-duty Truck Standards

As mentioned, many light-duty truck (LDT) manufacturers commented on one or both of the following emission control levels: 1.05 HC, 11.16 CO, 1.43 NOx g/km (1.7 HC, 18 CO, 2.3 NOx g/mi) or the proposed Canadian standard for passenger cars. For the sake of clarity, these standards will be referred to as proposed-I and proposed-II, respectively, in the following summaries of the manufacturer responses.

Chrysler Canada Ltd.

Chrysler commented to the proposed-II standard that "these standards are certainly not feasible for many light-duty trucks. Chrysler trusts that the government will establish separate, more realistic standards for trucks, if the standards must be tightened at all. The proposed standards are also not feasible for most diesel-powered vehicles with regard to NOx."

To meet the proposed-I standard, Chrysler identified an oxidation catalyst of larger volume as the primary change from their current truck models.

Ford Motor Company of Canada, Ltd.

Ford commented to the proposed-II standard that "the proposed Canadian standards for light-duty trucks would be more stringent than the most stringent standards likely to apply outside of California. The U.S. 49 state applications, which currently include all (with the exception of one unique 4.9 litre engine family) of the Canadian 0-6000 pound light-duty truck lineup, would no longer be available in Canada. In the current austere economic climate, unique Canadian calibrations are not economically feasible. Ford will have little choice but to develop all new California calibrations to meet the lower Canadian standards."

General Motors of Canada Ltd.

General Motors commented "It is anticipated for 1984 and future years, that with the U.S. light-duty truck standards set at 0.8 HC, 10 CO, and 2.3 NOx grams per mile, General Motors of Canada will be able to justify the recalibration of a significant portion of our light-duty truck sales to the less stringent current Canadian standards to reduce fuel consumption and cost. Lowering the NOx level to 1.0 gram/mile would preclude such recalibrations. In addition, as with passenger cars, it would be necessary to recalibrate the U.S.federal designs or select California engines for Canadian applications. Both of these options would result in an increase in fuel consumption and cost relative to models which meet existing standards and/or restrict product availability."

Nissan Motor Company, Ltd.

Nissan reported that if the proposed-II standards "will be applied to light-duty trucks, standards for LDTs sold in Canada will become more stringent than either the federal standards enforced by the United States Environmental Protection Agency or State of California standards enforced by the California Air Resources Board. In order to meet these proposed standards, the emission control systems of Canadian LDTs will become the most expensive of any in the North American markets."

Toyota Canada Inc.

Toyota reported that it would meet the proposed-I standard with oxidation catalyst systems, the same as it uses to meet current standards.

Volkswagen Canada Inc.

Volkswagen indicated that it will use an electronically fuel injected, closed-loop three-way catalyst system to meet the proposed-I standard.

3.33 Impacts of Proposed Light-Duty Truck Standards

Adoption of 1.05 HC, 11.16 CO, 1.43 NOx g/km (1.7 HC, 18 CO, 2.3 NOx g/mi) standards will result in little change in the emission control technology systems since most manufacturers already use oxidation catalyst systems. In these instances the primary change will be an increase in the volume and noble metal content of the catalyst. In a few cases, the systems may have to be upgraded from a non-catalyst to an oxidation catalyst system.

A very few manufacturers provided cost estimates for meeting the above proposed LDT standards. Table 3-12 presents Chrysler's estimate of retail price increase if the standards were adopted. The retail price increase reported by Chrysler is of the order of $ 42-58 (1983 Canadian dollars). This is a reasonable estimate for a catalyst redesign change.

Considering that the oxidation catalyst system still has emission control margin at the proposed LDT standard and the fact that little change in emission control system types is expected (most use the U.S. federal systems now) no change in fuel consumption, driveability, maintenance, or durability is expected.

In terms of lead-time, 12-18 months would be adequate since most manufacturers would adopt the current U.S. truck emission control systems.

TABLE 3-12

RETAIL PRICE COMPARISON OF ALTERNATIVE 1986 EMISSION CONTROL SYSTEMS FOR CANADIAN LIGHT TRUCKS

Feature	2.2L Engine - T110 1986 Base System 2.0 HC, 25 CO, 3.1 NO_x	2.2L Engine - T110 1986 New Proposal 1.7 HC, 18 CO, 2.3 NO_x		5.2L Engine 1986 Base System 2.0 HC, 25 Co, 3.1 NO_x	5.2L Engine 1986 New Proposal 1.7 HC, 18 CO, 2.3 NO_x	
Front Catalyst*	45 (10-0)	105 (12-0)	$48	None	None	
Rear Catalyst*	None	None	--	45 (10-0)	90 (10-0)	$42
Thermal	Underbody and dash panel heatshields	Extra heat - shielding	2	Heatshields	Heatshields	--
Air Injection	One upstream aspirator	One upstream aspirator	--	Dual upstream aspirators	Dual upstream aspirators	--
Spark Control	ESA	ESA	--	ECU	ECU	--
Carburetion	Standard	Standard	--	Standard	Standard	--
Idle Control	Sl[illegible]	Vacuum Kicker	8	None	None	--
Retail Price at 1983 Economics ($Canadian including 9% Federal sales tax)	Base Price	Base Price + $58		Base Price	Base Price +$42	

*Catalyst volume given in cubic inches, with precious metal loadings in parentheses in units of mg/in^3. Numbers separated by a hyphen denote Pt-Pd content, a colon denotes Pt:Rh.

Source: Chrysler Canada Ltd.

3.34 Summary and Conclusions for Light-Duty Trucks

Of the proposed changes considered in this study, adoption of 1.05 HC, 11.16, 1.43 NOx g/km (1.7 HC, 18 CO, 2.3 NOx gram/mile) for light-duty trucks would have the least impact. Most manufacturers already use the same or recalibrated version of the U.S. federal truck emission control systems for gasoline-engined LDTs and would use these systems to comply. Retail price increases will be of the order of $ 50 to recalibrate -- mainly increasing catalyst volume. No impacts on fuel consumption, maintenance, driveability, or durability are expected.

Manufacturers offering diesel engines would not have to make any changes as the diesel engine currently offered is capable of meeting the new standards as well.

Any standard more stringent than that above would have significant impacts on technology and cost -- especially, if they were as stringent as proposed for passenger cars. This is because these standards would be more stringent than any proposed by the U.S. EPA and manufacturers would have to adopt systems similar to those used in California.

4.0 Alternate Emission Control Standards

The contractual scope of work specified that alternate levels of emission control stringency should be investigated. Two major questions were postulated. At what level of emission standards would the use of catalysts be required by the most of the industry and at what level of NOx emission standards would the industry be required to use three-way catalyst technology? Additionally, analysis of separate standards for light-duty trucks and diesel-engined vehicles was required.

4.1 Industry Comments on Alternate Emission Standards

The questionnaire requested manufacturers to consider the two alternate levels of emission control stringency addressed above. While most manufacturers cooperated in providing a response, almost all manufacturers provided the same qualification to their response.

The industry pointed out that the Canadian automotive market is small in comparison to their U.S. market. This means that when it comes to making a decision as to whether to develop a separate emission control for the Canadian market versus adopting an emission control system being used in the United States, the decision is often made on economics. Thus, for a Canadian automobile or light-duty truck model whose sales number a few thousand or less annually, it may be more cost-effective to install a more expensive U.S. federal or California emission control hardware system, than to incur additional engineering and certification costs for development of a unique Canadian calibration.

Thus, many manufacturers stated that, if the current Canadian standards were set at any level more stringent than the current level, they would have little choice but to use the U.S. federal closed-loop, three-way catalyst systems. As discussed in previous sections of this report, many manufacturers already use this approach for their low sales volume vehicles.

The exceptions that the manufacturers made to the above statement concerned diesel-engined vehicles and light-duty trucks. In each case, the manufacturers urged separate and less stringent standards for these classes. The manufacturer comments are summarized below:

Chrysler Canada Ltd.

Chrysler already uses a mix of catalytic and non-catalytic control systems and does not foresee a potential for non-catalytic approaches at levels much more stringent than present. Chrysler acknowledged that "high cost multi-point fuel injection systems have potential" for much lower levels but added that "the unique development tooling and production costs would dissuade consideration for the small Canadian market." In commenting on recent non-catalytic developments, Chrysler added that "future higher compression, high swirl, lean-burn/fast-burn systems would appear to increase HC output, but may provide marginal reductions in NOx."

Chrysler offered the comment that if, or, when the European Community tightened their emission control standards, such a level could be a very cost-effective standard for Canada as well.

At 1.24 g/km NOx (2.0 g/mile), Chrysler indicated that it could comply with a larger oxidation catalyst, increasing retail price by about $ 90.

Ford Motor Company of Canada, Ltd.

Ford reported that any standard lower than 0.93 HC g/km (1.5 g/mi) would require catalyst usage for all engine families. Further, any standard below 1.24 NOx g/km (2.0 g/mi) would require the use of three-way catalysts on most engine families.

General Motors of Canada Ltd.

General Motors pointed out that GM passenger cars already use oxidation catalysts and that an HC standard significantly less stringent than 2.8 or 3.0 g/km (4.5 to 4.8 g/mi) would probably be necessary for most GM engines to avoid use of a catalyst. GM added "if the Canadian standard was reduced to 0.93 HC, 9.3 CO, 1.92 NOx g/km (1.5 HC, 15 CO, 3.1 NOx g/mile) we would probably not attempt to offer a lead-tolerant engine. However, customer concern for the price difference between leaded and unleaded gasoline will probably be a more significant factor than the emission standards in determining this breakpoint."

With respect to the control level requiring three-way catalysts, GM replied that if the standards were lowered to 0.93 HC, 9.3 CO, 1.24 NOx g/km (1.5 HC, 15 CO, 2.0 g/mile) they would probably require the use of a three-way catalyst on most engine-vehicle combinations.

Honda Canada Inc.

Honda suggested emission control standards of 1.12 HC, 12.4 CO, 1.55 NOx g/km (1.8 HC, 20 CO, 2.5 NOx g/mile) as levels that they could meet without major modifications to their current systems or significant cost increase. They would no longer be able to offer a lead-tolerant system at 1.25 HC, 9.4 CO, 1.25 NOx g/km (2 HC, 15 CO, 2 NOx g/mi). Up to this level Honda would be able to use their CVCC stratified charge engine with EGR.

Honda would be required to use three-way catalysts at either of the following standards: 0.26 HC, 2.1 CO, 0.63 NOx or 0.26 HC, 4.4 CO, 0.44 NOx in g/km. These correspond to NOx levels of 1.0 and 0.7 g/mile NOx respectively.

Mercedes-Benz of North America, Inc.

Mercedes-Benz urged that the NOx standard for diesels be no more stringent than 1.24 g/km (2.0 g/mi) and that 0.93 g/km (1.5 g/mi) was the technology limit for their turbocharged engines.

Renault USA, Inc.

Renault urges that the NOx standard be made no more stringent than 1.24 g/km (2 g/mi) as at this level they would be able to meet the standards with an oxidation catalyst and pulse air.

Peugeot

Peugeot reported that a NOx standard of 0.93 g/km (1.5 g/mi) is the practical limit for EGR control of their diesel engines.

Toyota Canada Inc.

Toyota reported that "because of various factors such as, fuel economy, driveability, etc., many of the engines in compliance with the current standards must use catalysts." The emission levels in which catalysts would not be needed would have to be 2.2 HC, 16 CO, 1.9 NOx g/km (3.54 HC, 25.7 CO, 3.06 NOx g/mi). For the lowest emission vehicles (belonging to the sub-compact class), the emission levels would have to be 1.2 HC, 12 CO, and 1.2 NOx g/km (1.93 HC, 19.3 CO, 1.93 NOx g/mi). Use of three-way catalysts would be required for comparatively heavier vehicles to meet 1.2 g/km NOx (1.93 g/mi) and for all vehicles to meet 0.62 NOx g/km (1.0 g/mi) standards.

Volkswagen Canada Inc.

Volkswagen reported that catalyst use is needed at 0.93 HC, 9.3 CO, 1.24 NOx g/km (1.5 HC, 15 CO, 2.0 NOx g/mi). Three-way catalyst systems would be required at NOx levels less than 0.93 g/km (1.5g/mi). With respect to diesels, Volkswagen indicated that it would have difficulty achieving NOx levels lower than 0.93 NOx g/km (1.5 g/mi).

4.2 Conclusions on Alternate Standards for Passenger Cars

Gasoline-fueled

As the standards are tightened, manufacturers will shift from non-catalyst designs to oxidation catalyst or U.S. federal three-way systems. At around 0.93 HC, 9.3 CO, 1.24 NOx g/km (1.5 HC, 15 CO, 2.0 NOx g/mi) all cars, with the exception of the very smallest (mini-compacts), will have shifted to the catalyst systems. The primary reason for this breakpoint is cost rather than limitations on technology. Electronic or continuous mechanical multi-point fuel injection systems, electronic computerized control systems, and thermal reactors are available technologies that would permit lower emissions. However, the high costs of these systems combined with development and certification costs, would make catalytic systems a more cost effective approach for a small market like Canada.

The breakpoint for the use of three-way catalysts appears to be around 0.93 NOx g/km (1.5 g/mi). Again, technologies are available to give lower emissions, especially for compacts and sub-compacts, but, for cost reasons, most manufacturers would opt to use U.S. federal three-way systems.

None of the manufacturers commented on the fuel consumption implications of establishing an alternate emission standard between current and proposed standards. It is the judgement of the authors that the average fuel consumption of the fleet would be greater than that of a fleet meeting the proposed standards. This judgement is based on the opinion that manufacturers would use more open loop systems and fewer electronic controls at the less stringent standard.

The industry comments on the need for catalyst systems are summarized in table 4.1.

Table 4-1

EMISSION LEVELS AT WHICH CATALYSTS FOR GASOLINE-FUELED VEHICLES ARE REQUIRED

(Grams per Kilometre)

Source	Oxidation Catalyst			3-Way Catalyst		
	HC	CO	NOx	HC	CO	NOx
Chrysler						1.24
Ford	0.93					1.24
General Motors	0.93	9.3	1.92			
Honda	1.25	9.4	1.25	0.26 0.26	2.1 4.4	0.63 0.44
Toyota (Heavy) (light)						1.2 0.62
Volkswagen	0.93	9.3	1.24			0.93
Authors' Assessment	0.93	9.3	1.24			0.93

Diesel-Engined Passenger Cars

The 0.93 NOx g/km (1.5 g/mi) level is also a significant breakpoint for diesel-engined passenger cars. More stringent levels may eliminate the large, eight cylinder diesels and would require most manufacturers to develop electronic EGR systems in lieu of mechanically-controlled EGR systems. Since the diesel markets are small in North America, some manufacturers might drop diesel models all together. This NOx level also represents a breakpoint where some manufacturers might need to utilize particulate traps if particulate standards are superimposed on the NOx standards.

4.3 Alternate Standards for Light-duty Trucks

The standards 1.05 HC, 11.16 CO, 1.43 NOx g/km (1.7 HC, 18 CO, 2.3 NOx g/mile) were originally selected by the U.S. EPA as levels that would not force the use of catalysts on light-duty trucks. However, many manufacturers have opted to use catalysts anyway. Since the oxidation catalyst systems are capable of much lower emissions, LDT standards could be reduced to around 0.5 HC, 6.2 CO, 1.43 NOx g/km (0.8 HC, 10 CO, 2.3 NOx g/mile) without forcing significant changes in technology usage.

Even lower standards could be considered for the mini-trucks -- levels equivalent to the passenger car standards -- as these vehicles are lower emitters to begin with.

The ramifications of standards lower than those in the U.S. are clear. Unless the U.S. federal standards are also reduced, model availability in Canada would be reduced and many manufacturers would use California emission control systems.

5.0 COLD WEATHER EFFECTS ON EMISSIONS

The terms of reference specified the investigation of technology that would provide more effective control of emissions under cold weather conditions than currently being achieved. The impact of adopting the proposed standards on cold weather performance will be evaluated and alternate scenarios discussed.

5.1 Background

The federal test procedure (FTP), which is used to measure pollutants and is the compliance yardstick for the emission standards, is based on a dynamometer test with a temperature range of 20 to 30 degrees Celsius (FTP median temperature is around 25 degrees Celsius). The U.S. Department of Transportation has estimated that 66% of all vehicle miles traveled falls below the FTP temperature range. This percentage is even greater in the colder climate of Canada.

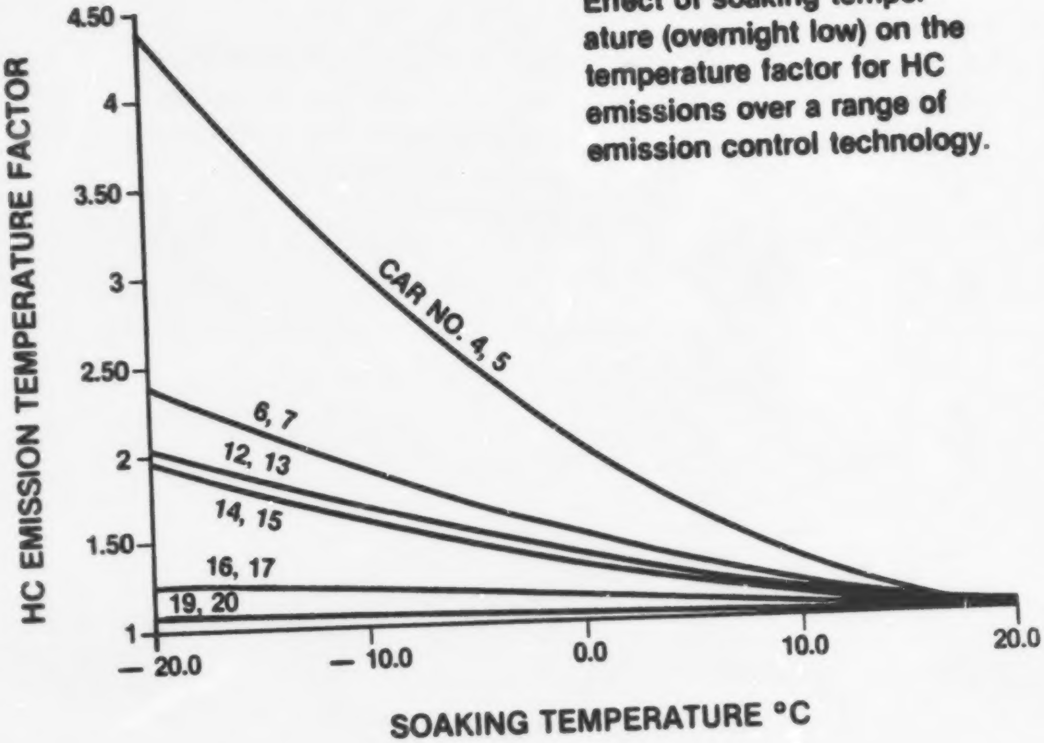
The well-known effect of increasing emissions with decreasing temperature and limitations of the FTP test temperature have concerned Environment Canada and the U.S. EPA. As a result of this concern, considerable cooperative testing at cold temperatures has been conducted by both agencies. It is not the purpose of this report to reiterate these findings but the following conclusions are typical of the results from these test programs:

1- Substantial increases in CO emissions result when vehicles are soaked at temperatures lower than those specified for the FTP. Most of the increased CO emissions come from the first few minutes of vehicle operation. On a gram per kilometre basis, the cold start portion of the FTP (bag one) contributes 81% of the total CO emissions at 24 degrees Celsius, but contributes 92% of the total CO emissions at minus 7 degrees Celsius. Results from testing programs prior to 1981 have shown CO to average more than 4 times higher at minus 7 than 24 degrees C.

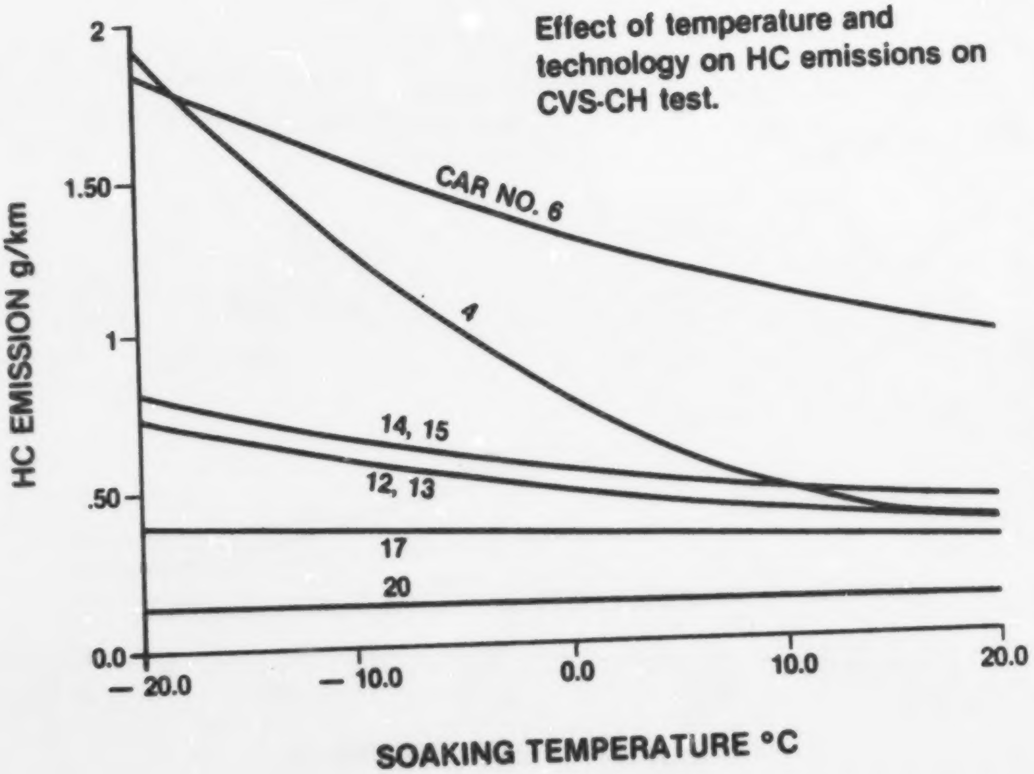
2- There are wide variations in the temperature sensitivity between vehicles; with the latest emission control technologies having markedly decreasing sensitivity to low temperatures. Engine type, emission control system design, and calibration strategy are all factors that influence temperature sensitivity. For example, two vehicles which are separated by less than 2 grams/mile at 24 degrees C can be almost 30 grams per mile apart at minus 7 degrees C.

These effects are illustrated in Figures 5-1 through 5-3. The test method used to compile the data shown in the figures was the official Canadian emission testing procedure (CVS-CH). Tests were conducted on 1975 and later model year vehicles at temperatures from -30 to +30 degrees C. The "temperature factor" is the multiple of the emission level that is measured at 20 degrees C; that is the temperature factor is 1 at 20 degrees C and increases as the soaking temperature decreases.

FIGURE 5—1



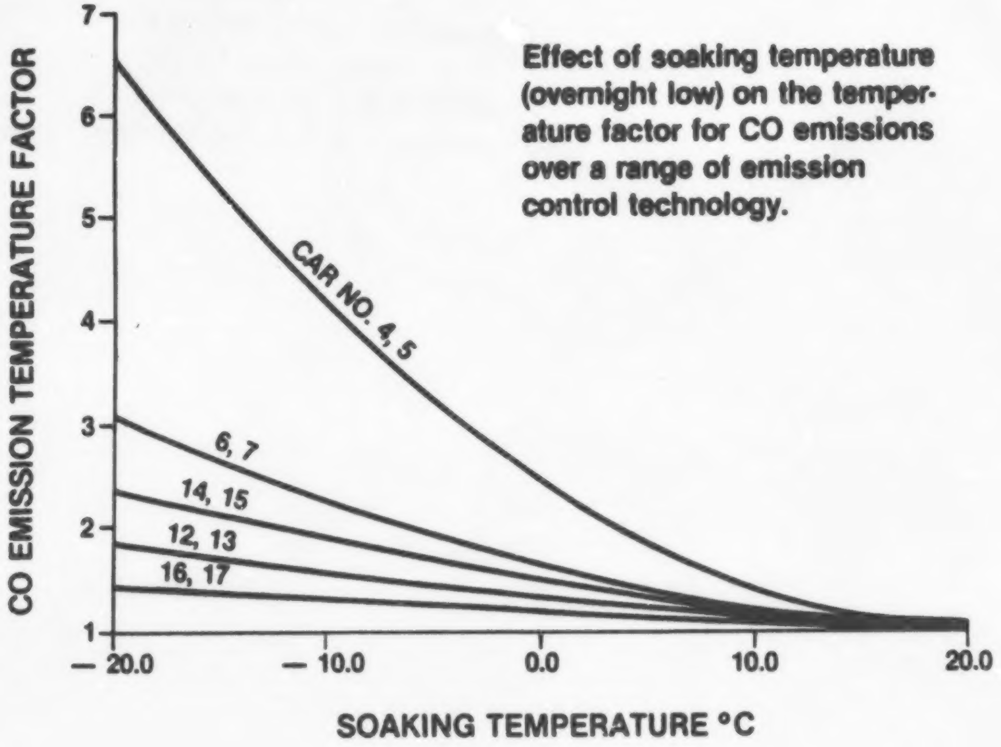
Effect of soaking temperature (overnight low) on the temperature factor for HC emissions over a range of emission control technology.

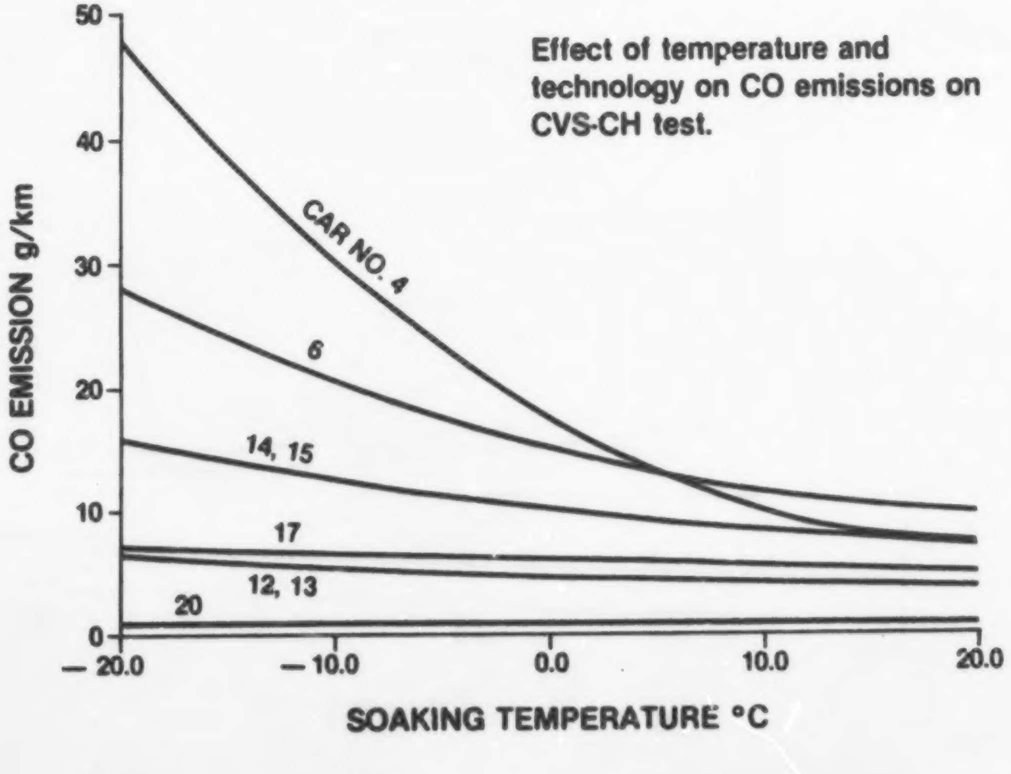


Effect of temperature and technology on HC emissions on CVS-CH test.

Source: Ostrouchov (1980)

FIGURE 5—2

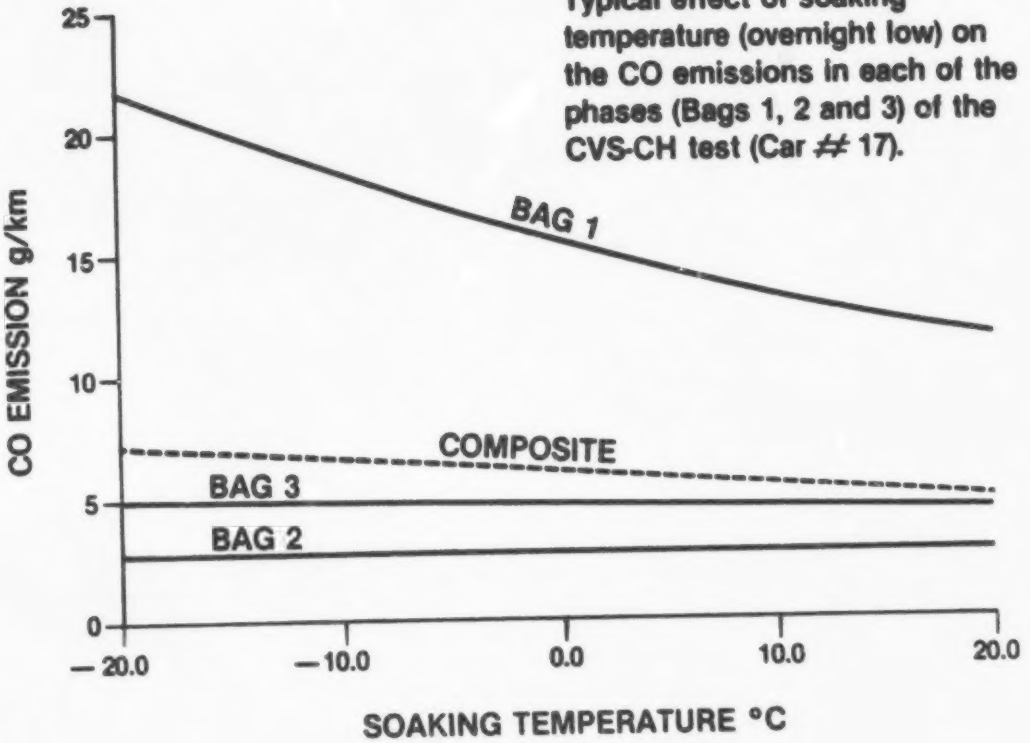

Effect of soaking temperature (overnight low) on the temperature factor for CO emissions over a range of emission control technology.


Effect of temperature and technology on CO emissions on CVS-CH test.

Source: Ostrouchov (1980)

FIGURE 5—3

Typical effect of soaking temperature (overnight low) on the CO emissions in each of the phases (Bags 1, 2 and 3) of the CVS-CH test (Car # 17).



Source: Ostrouchov (1980)

Modern emission control system effectiveness at cold temperatures depends on two primary considerations: the nature of the engine's engine-out emissions, and the efficiency of exhaust aftertreatment systems. Unfortunately, vehicle operation at cold temperature increases engine-out emissions and decreases the effectiveness of aftertreatment systems. In general, however, the emissions reductions obtained at the official test temperature of 20° C as a result of more stringent standards has also resulted in proportional reductions in emissions at temperatures representing Canadian winter conditions. (reference 14)

There are several technical reasons why CO emissions tend to get worse as the ambient temperatures decrease. Even at the warm temperatures that characterize the cold start portion of the FTP, vehicles have cold start problems. This is because the volatility of fuels must be compromised for the large temperature difference between the normal engine coolant operating temperature of about 92 degrees C, and the ambient temperature which is also the initial temperature of the engine at cold start. Thus, there can be a 70 to 100 degrees C spread between ambient and engine operating temperature with the difference increasing with decreasing ambient temperatures.

This compromise in volatility means that at cold start not all of the fuel that is metered to the engine vaporizes completely and even vaporized fuel can condense on cold surfaces of the intake manifold system. The result is that the cylinders of the engine operate on an air/fuel mixture that is significantly leaner than the air/fuel mixture that was metered by the carburetor or injector. The required difference in air/fuel ratio on cold start is provided by choking the carburetor or increasing the fuel flow in an injection system. As an example, using equilibrium air distillation (EAD) curves as a simulation of the process that occurs in a real engine, at 15 degrees C an air/fuel ratio of 8:1 is needed to get an air/fuel vapor ratio of 20:1. At lower temperatures; e.g. -7 degrees C, the air/fuel ratio needed to get a 20:1 air/fuel vapor ratio is 1:1.

The condensed fuel is either swept into the engine as liquid droplets where it is burned inefficiently or slowly evaporates as the engine warms up, resulting in excessively rich mixtures in the later stages of warmup.

In addition, other portions of the vehicle system are affected by cold weather. Battery cranking power drops, lubricant viscosity increases, and engine friction increases, making starts more difficult. The engine will require a longer warmup time at colder temperatures with longer periods of cold start enrichment.

The aftertreatment system, typically a catalyst, also needs to warm up to be efficient. Light off temperature (the temperature at which the catalyst has 50% CO oxidation efficiency) is around 250 degrees C. At an ambient temperature of 25 degrees C, light off temperatures can be reached in less than one minute, while at cold weather temperatures it can take several minutes. Under inclement weather conditions contact between the catalyst and exhaust system and rain or snow can cause even longer warm up periods.

5.2 Emission Control Technology to Reduce Cold Start Emissions

5.21 Air/Fuel Metering and Preparation Systems

Design of the air/fuel metering and preparation system is possibly the most important and difficult task in controlling cold start emissions. In the past, the ability to precisely meter the right amount of fuel during start up was constrained by the inflexibility of mechanical choke designs and conventional carburetors to vary air/fuel ratio accurately. The development of electronically-controlled carburetors and fuel injection systems has made it possible to overcome these constraints. For example, it is now possible not only to more precisely control air/fuel ratio, but also to map the air/fuel ratio and spark timing requirements for an engine during cold start as a function of ambient temperature and to pre-program the optimal settings in the memory of a microcomputer. The industry has expended much work over the years on FTP calibration strategies for good emissions performance. While not much detail has been reported on this work, less or no work has been reported on the calibration strategies needed for emission control at cold temperature. This suggests that the potential for electronic control with pre-programmed calibration strategy remains to be fully investigated.

Electronic control can also aid in cold start emissions control by providing a precise means of controlling the spark advance schedule, the air injection schedule, EGR lockout during cold start, the idle speed schedule, and engine coolant flow control. At present, control of these systems is not proportional with engine temperature -- mostly, it is a matter of fixed settings or on/off conditions. For example, engine coolant temperature is controlled by a bimetallic spring which begins to modulate flow only when the engine is fully warmed. At other times the flow is controlled by a fixed orifice and the fixed by-pass flow to the passenger compartment heater. With electronic modulation of a coolant regulator valve the engine could be warmed up faster by only allowing circulation of water to the engine and intake manifold during cold start.

Some studies have suggested that a significant source of CO emissions is due to the long periods of engine idle that is often characteristic of inclement weather during winter. Electronic automatic shut-off and restart of engines to prevent long periods of idle has already been used in a limited production application.

Another critical part of the air/fuel delivery system is the intake manifold. Fast warm up of the manifold is important if fuel condensation is to be avoided. A large number of devices to speed intake manifold warm up have been developed and many remain to be used in OEM applications. These devices fall into three categories: thermal, electrical, and mechanical.

Thermal devices typically use exhaust heat to warm up a heat transfer plate below the carburetor. General Motor's Early Fuel Evaporation (EFE) systems are an example of thermal devices.

Electrical systems involve the use of a grid that is electrically heated to assist in fuel evaporation. Texas Instruments (TI) makes a ceramic grid that is electrically heated and which is in us on a few production cars. Engine block heaters, which are a popular aftermarket device in the colder regions of Canada, also fall into this category. In this case, the prewarmed engine coolant also keeps the intake manifold warm since most intake manifolds have intake cooling passages.

Mechanical approaches rely on atomization instead of evaporation. Here the approach is to make the fuel droplets tiny enough so that they go along with the air, thus, allowing enrichment to be reduced. A considerable amount of effort has been devoted to this area over the last 50 years. In fact, the proliferation of inventor devices in this area may be a negative restraining factor on industry evaluating them, since so many have been proven to be inadequate. However, three novel devices appear worthy of evaluation. They are the spinning cup or disc, the Hartmann whistle, and the slotted sphere. The principles of operation are either centrifugal force or thin film air atomization.

5.22 Aftertreatment System Modifications

It has been shown that catalysts can be made more efficient during cold start by using techniques that provide quick warm up of the catalyst. They have not been used to any large extent in production because of cost or interferences with vehicle chassis design.

Palladium and rhodium exhibit better light off characteristics than platinum and increasing the loadings of these materials in catalysts may be an effective strategy. No major hardware changes are required, but, increased noble metal loadings, especially rhodium, add to the cost of a catalyst.

The use of a smaller start catalyst or segmented catalyst consisting of two parts would allow much faster catalyst warm up. Positioning of the start catalyst or main catalyst as close to the engine as possible would further enhance warm up. These approaches have not been popular because start catalysts may have to be switched out of the exhaust system during normal operation to prevent overheating and location of the main catalyst closer to the engine often requires redesign of the frame or chassis.

Finally, some manufacturers employ pellet catalysts which tend to warm up more slowly than monolith catalysts. These manufacturers would have the option of switching catalyst types for cold start emissions control.

5.23 Fuel Modifications

Another technology category for reducing cold weather emissions involves fuel modifications that increase the volatility of the fuel. Petroleum refiners already make seasonal adjustments to the volatility of motor fuels by changing the low boiling point fractions in the gasoline blend. Light ends like butane are commonly used. It is possible that further additions of light ends, above and beyond what is currently done, might be possible for extremely cold areas experiencing CO hot spots. Mobil has developed an on-board system which partially distills liquid fuel when the vehicle is operating and stores the lighter ends for startup.

Finally, some gaseous fuels need no cold start enrichment at all. Ford Motor Company has developed propane fueled vehicles, some of which have been sold in Canada. This option would be attractive if the propane distribution and refueling network were expanded and if the costs of propane on a cost per kilometre basis continued to be lower than gasoline. At the present time, most propane users are operators of large motor vehicle fleets.

5.24 Comfort Improvements

There is some reason to believe that a fraction of the cold weather CO emissions is attributable to the practice of some motorists of idling the engine unattended to prewarm the passenger compartment and to facilitate the removal of ice and snow from the windshield. The use of electrical defrosting (similar in concept to the electric hair dryer) and electric car seat heaters might alleviate this practice.

5.3 Manufacturer Comments on Cold Weather Emissions

Ford Motor Company of Canada, Ltd.

Ford commented that "the limited amount of cold ambient CVS testing conducted by Ford indicates that fuel injection systems exhibit significantly lower cold temperature emissions than do conventionally carbureted systems. In addition, cold temperature emissions might be further reduced by secondary air strategy revisions as well as leaner operations."

General Motors of Canada Ltd.

General Motors replied that "we do not have any devices readily available which we would expect to significantly reduce cold start emissions. The present room temperature test requirements in combination with our objectives for starting under real world cold weather conditions continue to be a challenge. We do not believe that any additional regulatory action will result in fast development in this area. For the future we are optimistic that open loop and closed loop electronic emission control systems can be developed that overcome the mechanical limitations which currently exist. Such systems offer the best opportunity for tailoring transient low temperature fuel control more precisely to minimize emissions during warm-up without resulting in customer inconvenience due to failure to start and run."

Honda Canada Inc.

Honda expressed the opinion that it is not possible to modify choke systems toward leaner operation without incurring degraded driveability. Honda believes that the following approaches would be effective in reducing cold start emissions:

a) Rapid warming of intake manifold riser,
b) Low-temperature-activated catalyst and oxygen sensor,
c) Finer control choke system, and
d) Engine modifications to permit improved combustion at cold engine conditions.

Toyota Canada Inc.

Toyota stated that "we have no quantitative data with which to discuss measures to reduce cold emissions, but we do think that a leaner A/F ratio and quick warm-up of the catalyst are necessary to reduce cold emissions. In order to obtain a leaner A/F ratio, precise control of the choke system and improvement of intake air heating and so on, will be necessary. However, a great deal of difficulty is anticipated in trying to obtain a leaner A/F ratio without harming driveability. With respect to quick warm-up of the catalyst, we think that adoption of a start catalyst and raising of exhaust temperature, etc., are necessary, but these measures are estimated to have penalties of cost, fuel economy, etc."

Volkswagen Canada Inc.

Volkswagen indicated that their continuous injection system (CIS), that is used on Volkswagen and Audi NSU products, provides the best distribution of fuel between cylinders and allows rapid switch to lean conditions on start-up. The addition of closed loop control, according to Volkswagen, also reduced the transition time to lean operation and produced substantial reductions in CO emissions. Volkswagen concludes that further enleanment of the system during cold start is impossible.

5.4 Alternate Strategies for Controlling Cold Weather Emissions

A number of alternate strategies have been identified, but, no alternate strategy offers the perfect solution or, perhaps, even enough advantage to consider changing the current strategy.

Require Cold Temperature Testing

The most obvious alternate strategy is to require the manufacturers to perform cold temperature testing either as an adjunct to the current compliance procedures or as a replacement for the current compliance program. A major drawback to this strategy is cost. Unless the compliance procedures allowed natural soaking and testing outdoors and the manufacturers were willing to restrict their testing during winter months in a cold geographic climate, the industry would have to procure and install refrigerated test cells. The authors estimate that a two-dynamometer cold room test cell would cost about one million dollars. Certainly a large manufacturer like General Motors could afford the investments involved, but, even General Motors would have to allocate the increased capital and operating costs over a relatively small annual sales volume (approximately 290,000 vehicles in model year 1982). The authors estimate that General Motors would require around ten such cells for certification and development, so that interest and depreciation for the test cells alone would run 2 to 3 million dollars annually, or ten dollars per unit sold. Operating and maintenance costs would easily double since it takes more time to run the cold weather tests and to maintain the equipment. We estimate that these increased operating and maintenance costs could add another $30 to 40 per unit sold in General Motors case. Of course, these estimates are qualitative, and more detailed cost estimating would be required if this option were selected for further consideration.

Modify the Test Procedure

In the current test procedure the cold start portion of the test is weighted at 43%. A alternate strategy would be to place greater emphasis or heavier weighting on the cold start portion for purpose of CO compliance. This would result in the installation of control technologies (e.g. start catalysts) that would bring about reductions at cold temperatures. This strategy has merit but further study is required to determine the actual shift in weighting required to force installation of effective control technologies.

Issue Design Standards

Design standards could be developed that would require the installation of certain emission control technologies that have been shown to be effective at cold temperatures. For example, it could be a requirement that all automobiles be equipped with one or more of the following controls: start catalysts, block heaters, electronic computer control of choke and spark timing, and so on. The major drawback to this strategy is that the regulatory agency would have to develop the expertise needed to specify design standards and it would inhibit industry freedom and innovation. A variation could involve the development of design standards by an engineering society such as SAE, but, such an approach would take considerable time.

Optional Cold Weather Testing

The industry could be offered the option of compliance testing their vehicles at cold temperatures. To make this option attractive other standards or areas of compliance would be relaxed. For example, a manufacturer taking this option could receive a NOx waiver from 0.63 g/km to 1.24 g/mi. The disadvantages of this approach are that the incentives that would have to be given a manufacturer would be severe enough as to cause an air pollution problem in another area and it would take time and resources to develop cold weather standards and test procedures.

Emission Control System Device Certification

Under this strategy a manufacturer would need only to certify a cold weather emission control package(s) rather than certify each and every car model. The manufacturer would have to install certified packages on each car or cars sold in selective geographic areas. The advantages are that costs of certification are greatly reduced and some of the packages may prove to be effective retrofit devices. The disadvantages are that there is no assurance that the system will work on all of the manufacturers models and enforcement against non-complying models becomes almost impossible.

6.0 EFFECTS OF FUEL COMPOSITION CHANGES ON EMISSIONS

The terms of reference anticipated that examination would be made of the effects of future years' fuels on automotive emissions. However, early discussions with the sponsoring agencies, especially Energy, Mines and Resources Canada, resulted in the conclusion that fuel composition was not likely to change significantly within the time frame of interest for this study. It was decided that the only fuel compositional effects to be studied would be limited to the effects of the fuel antiknock additive, methylcyclopentadienyl manganese tricarbonyl (MMT), and any fuel compositional effects that the automotive industry identified during the course of the study.

6.1 Emission Effects of the Antiknock Additive MMT

6.11 Background

Since 1975 most cars produced in the United States have been equipped with catalysts that require the use of unleaded gasolines. In order to maintain the octane quality of motor gasolines many refiners began to use MMT as a substitute for tetraethyl lead. In anticipation of MMT usage and concern over the lack of emissions data on MMT-containing fuels, the U.S. EPA notified the automotive manufacturers, on January 7, 1977, that MMT would be required in vehicle certification fuel beginning with the model year 1979. Since early tests run in 1976 by the automotive industry suggested that MMT could, under certain operating conditions, cause plugging of the catalyst, the industry became concerned that they might not be able to meet the Clean Air Act mandated hydrocarbon standard of 0.41 grams per mile.

As a result of the EPA action and industry concerns (that quickly spread to include the refiners and manufacturers of MMT) a crash test program was initiated to determine the emission effects of MMT. The test program was a cooperative effort by the Coordinating Research Council (CRC) with sponsorship through the Motor Vehicle Manufacturers Association, and the American Petroleum Institute.

The program involved 63 cars which accumulated over 4.8 million kilometres (3 million miles). The primary objective of this program was to determine the effect of two different concentration levels of MMT on catalytic converter plugging, catalyst conversion efficiency, oxygen sensor life, and spark plug life.

In addition, some automobile and fuel additive manufacturers operated smaller fleets on MMT fuels.

6.12 CRC Program Results

The results and conclusions of the CRC test program are available as a CRC report (reference 6) and only the key findings will be summarized here.

Tailpipe Hydrocarbon (TPHC) Emissions

The MMT-fueled cars averaged significantly higher tailpipe HC levels compared to the cars operated on clear fuels. The average tailpipe emissions measured at 80,600 kilometres (50,000 miles) were 0.06 and 0.07 HC grams per kilometre higher (0.09 and 0.11 g/mile), for 1/32 grams MMT/gallon (U.S.) and 1/16 grams MMT/gallon (U.S.) respectively, for the MMT fueled cars than the clear-fueled cars. The differences in the tailpipe hydrocarbon emissions for the MMT fueled versus clear-fueled cars increased steadily for the first 25,000 kilometres and then remained constant at about 0.06 grams per kilometre. The same general pattern of emissions increase was observed for both oxidation and closed-loop three-way catalyst cars.

Engine-Out Hydrocarbon (EOHC) Emissions

The vehicles operating on MMT fuels averaged significantly higher engine-out HC levels than did the vehicles operating on clear fuel. The average EOHC emissions for the MMT-fueled cars at 80,600 kilometres (50,000 miles) were 0.30 and 0.49 grams/kilometre higher (0.48 and 0.79 grams/mile) for 1/32 MMT and 1/16 MMT respectively, than the EOHC emissions for the clear-fueled cars. The differences in the engine-out hydrocarbon emissions for the MMT-fueled versus the clear-fueled cars increased rapidly for the first 25,000 to 50,000 kilometres and then leveled out at 0.26 and 0.43 g/km for the 1/32 MMT and 1/16 MMT fuels respectively. The EOHC data show a consistently linear MMT concentration effect, in contrast to the results found for tailpipe HC. The same general patterns were found for both oxidation and closed-loop three-way catalyst cars.

Carbon Monoxide and Nitrogen Oxide Emissions

No significant fuel effects on CO or NOx tailpipe or engine-out emissions were found for the total fleet or the oxidation and three-way catalyst segments of the fleet.

Catalytic Converter Efficiencies

The MMT-fueled cars averaged 1.0 to 4.3% better catalytic conversion efficiencies for hydrocarbons compared to the clear-fueled cars. It is unknown whether these differences are due to an enhancement in converter activity with MMT or a difference in feed gas compositions or some combination thereof.

Catalytic converter efficiencies for CO and NOx were not significantly different between the MMT-fueled and clear-fueled cars.

Other Effects

Oxygen sensors in three-way catalyst vehicles were removed and inspected whenever unusually high CO emissions were found. While the sample size was limited, it was concluded that MMT had adverse effects on oxygen sensor life.

A secondary objective of the test fleet was to determine whether MMT fuels plug catalysts. The test procedure involved measuring the pressure drop across the catalyst during a 0 to 80 kilometre/hour wide-open throttle acceleration. As a result of these tests it was concluded that any differences between the test results were within the error of measurement and that plugging did not occur with any of the fuels.

6.13 U.S. EPA Findings and Conclusions on MMT Use

EPA also participated in the CRC study by providing assistance in the statistical design of the test plan and analysis of the test results.

In addition, Ethyl Corporation filed in 1978 for a waiver of the provisions of the Clean Air Act which prohibits the use of MMT after September 15, 1978. The Administrator of EPA denied the Ethyl use petition on the basis that "I have determined that Ethyl has not established that MMT at the specified concentrations of 1/16 and 1/32 grams of manganese per gallon and the emission products thereof will not cause or contribute to a failure of any emission control device or system (over the useful life of any vehicle in which such device or system is used) to achieve compliance by the vehicle with emission standards"(reference 7).

More specifically, EPA found that (reference 8):

1- MMT must be strongly suspected of having an adverse effect on oxygen sensor performance which leads to increased HC and CO emissions from three-way catalyst systems.

2- The phenomena of catalyst "enhancement" by MMT cannot be considered as a phenomena that eliminates the negative effect of MMT, or makes the use of MMT an overall benefit.

3- The combustion chamber deposits resulting from MMT use cause an increase in engine-out emissions.

4- The data do not show a direct effect of MMT on fuel economy, but a fuel consumption penalty could result if the manufacturers had to recalibrate their vehicles because of engine-out HC increases due to MMT use.

5- There is some increasing potential for catalyst plugging with continued use of MMT in vehicles that are operated with a high load factor.

Subsequently, Ethyl Corporation filed another petition with EPA to allow the use of MMT at concentrations of 1/64 grams/gallon or less. EPA again denied the petition mainly on the basis of insufficient data at these low levels of MMT.

6.14 Manufacturers Responses to Questionnaire

Chrysler and General Motors provided comment on the MMT issue based mainly on the CRC data.

General Motors stated "our primary concern in the near term is that the use of MMT should be discontinued from Canadian unleaded regular and premium gasolines if the very stringent 0.25 HC grams/kilometre level is mandated. MMT increases the HC level generated in the combustion chamber by about 0.07 grams/kilometre according to the findings of a joint EPA/CRC testing program which was conducted in the U.S. several years ago. At the 0.25 HC grams/kilometre level, General Motors could no longer be technologically capable of providing a safety factor in its emission system designs to account for the possibility of vehicles using fuels containing MMT."

In Chrysler's experience, MMT has been found to adversely affect motor vehicle emission control systems in three ways. These are by increasing HC emissions, plugging catalysts, and deteriorating oxygen sensors. Chrysler therefore opposes the use of MMT in gasoline at any level. Chrysler also indicated that their main objection to the use of MMT is that engine-out hydrocarbon emissions increase with MMT, even at the concentrations as low as 1/64 grams Manganese per gallon of gasoline.

6.15 Conclusions on MMT Effects

The consensus of EPA and the automotive industry is that MMT produces significant adverse effects on HC emissions. It is the judgement of the authors that it would be very difficult for manufacturers to certify vehicles at the proposed levels unless the HC standard were relaxed to compensate for the predicted HC increases. However, the authors are especially concerned with the potential for premature failures of oxygen sensors if MMT fuels are used. Admittedly the CRC study of effects on sensors involved only a few first generation sensors, but the results suggested accelerated failure of sensors. The CRC results were based on seven 1977-78 model year cars, all of which were calibrated to meet California standards. Advances in sensor technology since then may have alleviated some of the problem. If the sensor prematurely fails on a three-way catalyst system, feed-back control is lost. Unless the micro-computer control system is pre-programmed to adjust the air/fuel ratio under sensor failure conditions, excessive CO emissions will result. On the other hand, if the system is pre-programmed to operate at lean air/fuel ratios then NOx control is sacrificed.

6.2 Other Fuel Composition Effects

The only other major fuel composition concern expressed by the industry involved diesel fuels. Mercedes-Benz, in particular, provided extensive comment and a technical report (reference 9) on diesel fuel quality and it's impact on emissions. Mercedes-Benz would like to see regulation or tight specification of diesel fuel quality and urges that "the Ministers of Environment and Transport authorize a study of the relationship between diesel fuel and engine emissions and how preservation or improvement in diesel fuel quality would serve as a cost effective means of achieving lower diesel emissions."

Mercedes-Benz's concern stems from the fact that growing demand for middle distillates by non-transportation users (e.g. the chemical industry) may outstrip the fractional distillation yield of diesel fuel and other middle distillates from crude oil. This may require refiners to increase the heavier components of diesel fuel and to produce diesel fuels by cracking (thermal, catalytic, etc.) or reforming other crude oil components. EPA contractor studies (reference 10) have suggested that initial use of synthetic crudes derived from tar sands and coal might be used as direct blends (with hydro-treating) with diesel fuels.

The diesel fuel parameters that can have an impact on diesel exhaust emissions are ignition quality, boiling range, sulfur content, aromatic content, cold temperature properties, density, viscosity, and ash content. These parameters are important to the emission control of a diesel engine because they can influence ignition timing; the quality of combustion; the atomization, quantity and distribution of fuel from the injectors; the composition and extent of smoke, particulate, and odor formation; and the wear of emission control related engine parts.

Ignition Quality

Ease of fuel ignition in a diesel engine is measured as a cetane number with larger cetane numbers providing shorter times between injection and self-ignition of the fuel. Figure 6-1 represents data provided by Toyota which illustrate that exhaust emissions of CO and HC can increase significantly with decreasing cetane number, especially with cetane values lower than 45. Mercedes pointed out that in Germany a minimum cetane number of 45 is specified while in Canada some refiners were having problems meeting the 40 cetane number minimum specified in CAN2-3.6-M78 (reference 11).

Boiling Range

Typical diesel fuel boils in the range of 180 - 360 degrees C, with considerable variation worldwide. While the diesel engine is more tolerant of the boiling point range than the gasoline engine, the final boiling point of the diesel fuel blend is important to the formation of smoke and particulates. If the boiling point is extended to 380 or higher degrees C considerable smoke and particulate may be formed.

Aromatic Content

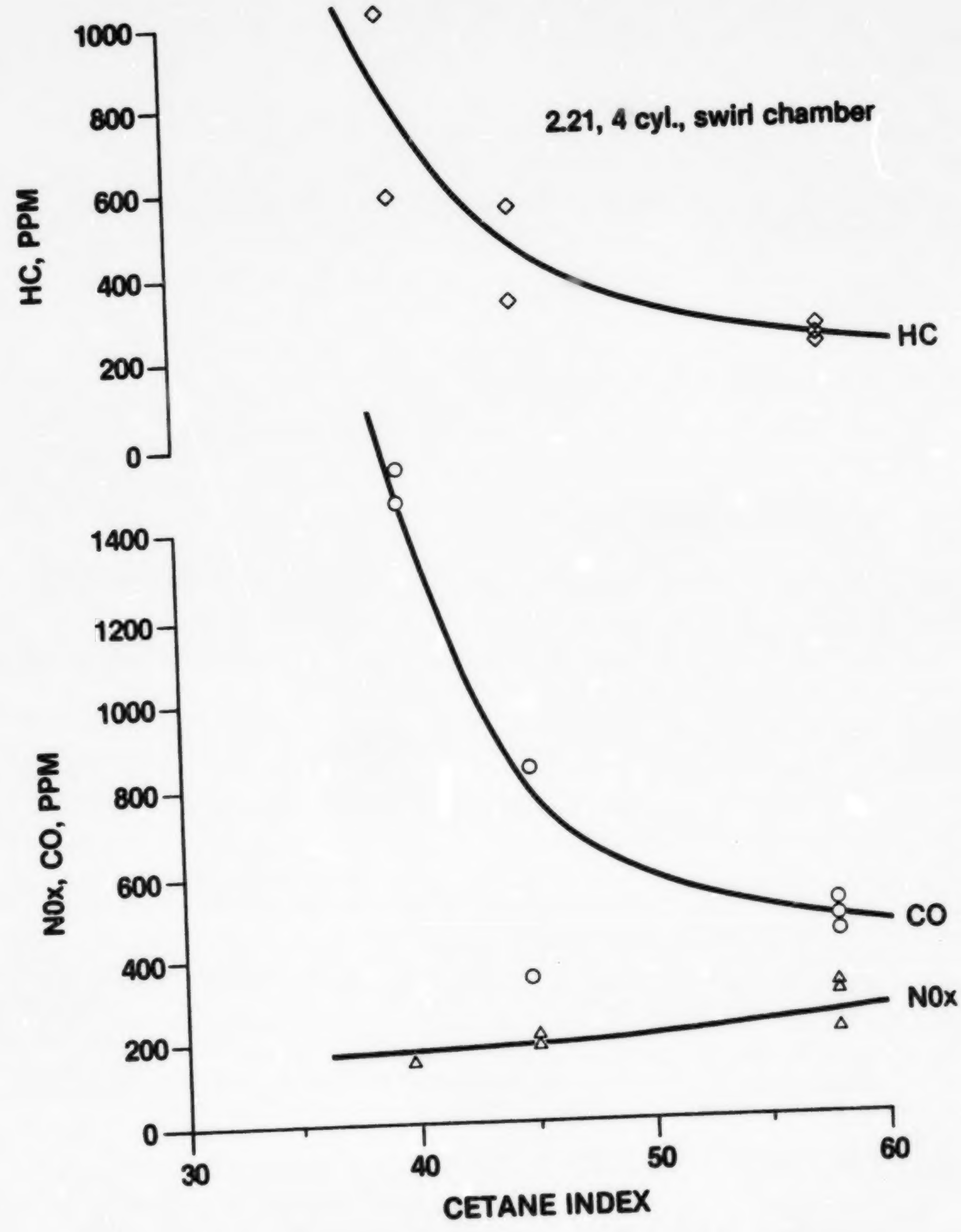
The aromatic content is important to the emissions of phenols and polynuclear aromatic (PNA) compounds, such as benzo-alpha-pyrene (BAP), with these emissions increasing with aromatic content. Diesel fuels blended from synthetic crudes in the future could have higher aromatic contents.

Sulfur Content

The sulfur content of diesel fuel is significantly higher than that of gasoline (up to 25 times higher) and is controlled at the refinery by blending crudes and hydro-desulfurizing the products. Since the oxides of sulfur are corrosive, they can cause wear and lubricant deterioration. More important from the emission control consideration is the hindrance posed by sulfur to the development of catalytic particulate traps. Besides potentially poisoning the catalytic material, considerable quantities of the sulfur oxides can be converted to sulfates by the catalyst.

FIGURE 6—1

JAPANESE 6 MODE DIESEL EMISSIONS



Source: Toyota Canada Inc.

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APPENDIX

QUESTIONNAIRE

for

EMISSION CONTROL TECHNOLOGY STUDY

Study being performed for:

ENVIRONMENT CANADA AND TRANSPORT CANADA

PILORUSSO RESEARCH ASSOCIATES, INC.
Suite 603
347 Bay Street
Toronto, Canada M5H 2R7

QUESTIONNAIRE

AUTOMOTIVE EMISSION TECHNOLOGY

Background

Environment Canada and Transport Canada jointly announced in the Canada Gazette, Part 1, on September 18, 1982, that it would examine the regulations restricting automotive exhaust emissions of oxides of nitrogen (NO_x), carbon monoxide (CO), and hydrocarbons (HC) for the purpose of deciding whether or not to revise these regulations for light duty passenger cars and trucks. The firm of Pilorusso Research Associates, Inc. was awarded a contract to perform the portion of the study dealing with automotive emission control technology and related costs. Mr. John DeKany, an independent engineering consultant, and Mr. Felix Pilorusso will be the principal investigators.

The purpose of the automotive emission technology task is to gather and analyze data on the exhaust emission control hardware and related direct cost factors required for more stringent control of automotive emissions in Canada. The study will be based on existing data, and this questionnaire has been prepared to allow your company and other members of the automotive industry to provide input and comment to the study.

Scope of Questionnaire

Three levels of emission control stringency will be studied --currently-applicable emission control standards, emission control standards proposed for vehicle compliance in 1986, and an emission control standard intermediate between these values. The basic request in the questionnaire is identification of the emission control hardware that your company uses to comply with the current standard and the emission control hardware that in your company's estimation would be required to meet the proposed and intermediate standards. Cost, fuel consumption, lead-time, vehicle durability and reliability, and special maintenance data are also part of the basic request.

Two other issues will be investigated in the emission control technology study -- one dealing with the effects of the colder Canadian climate upon emission control hardware performance, and the other with emissions changes resulting from future modifications in fuel composition.

Thus, if your company possesses data relating to the above issues, you are invited to complete the appropriate sections in the questionnaire and to submit reports, technical papers, and other studies.

Definitions and Nomenclature

Metric units are used throughout the questionnaire, e.g., emissions are expressed in grams per kilometre (gm/km), fuel consumption as litres per 100 kilometres (L/100km), and vehicle weight as kilograms.

The nomenclature for emission standards and test data is a triplet abbreviation. For example, the current emission standards of 1.24 grams of hydrocarbon per kilometre, 15.5 grams of carbon monoxide per kilometre, and 1.92 grams of oxides of nitrogen per kilmetre are abbreviated 1.24 HC, 15.5 CO, 1.92 NO_x with the understanding that the dimensions are grams per kilometre.

The passenger car exhaust emissions standards that will be examined in this study are:

Current	1.24 HC, 15.5 CO, 1.92 NO_x
Intermediate	To be determined by the study (a level not requiring Catalyst use)
Proposed	0.25 HC, 4.35 CO, 0.62 NO_x

The light duty truck exhaust emission standards that will be examined in this study are:

Current	Same as passenger cars above
Proposed	1.05 HC, 11.16 CO, 1.92 NO_x

In addition, the technology to meet an evaporative emission standard in the range of 2 to 4 grams per shed test will be evaluated.

The current exhaust emission standards are the values that are presently in effect. The proposed emission standards are those values which were published in the Canadian Gazette, Part 1, on 18 September 1982. An intermediate emission standard will be determined from analyses of data evaluated during the study, based on the criterion that the intermediate standard should not force substantial use of catalyst technologies. "Substantial use" is defined as use of catalysts in greater than twenty-five percent of vehicle production.

The definition of cost varies considerably, depending upon the cost accounting principles and the definitions employed. For consistency of analyses, it is requested that costs for emission control hardware be reported as the aggregate of the the following cost components:

- Out-of-pocket cost for purchased components, parts, etc.;
- Direct materials costs;
- Direct labor; and,
- Direct overhead for labor and materials.

In order to allow computation of the costs to consumers, it is also requested that you provide a markup factor that would include the balance of the cost components, including, as appropriate, indirect costs and burdens, general and administrative expenses, and profits.

Reported costs should be in 1983 dollars (Canadian).

Submission of Completed Questionnaires

Many companies have already submitted data to Environment Canada or Transport Canada and this data will be included in the study. Messrs. DeKany and Pilorusso will try to complete the questionnaire on the basis of these submittals and information received during visits to manufacturers with facilities located in Canada. However, in the interest of accuracy and completeness, it would be appreciated if your company could complete the questionnaire in its entirety. If a section or question in the questionnaire requests data already submitted, an appropriate reference to the submittal would be adequate and very helpful. A target date of April 20, 1983 is set for completion of the questionnaires.

If you elect to complete the questionnaire, please return by April 20 to Messrs. DeKany and Pilorusso during their visit to your company or mailed to the following organization and address:

Pilorusso Research Associates, Inc.
Suite 603
347 Bay Street
Toronto, Canada M5H 2R7

If you have any questions, you can discuss these with Mr. DeKany by telephone on (301) 864-7285 or (301) 277-8600 or by correspondence with the above office.

EMISSION CONTROL TECHNOLOGY QUESTIONNAIRE

PART A - GENERAL INFORMATION

Company Name: ______________________________

Company Address: ______________________________
____
____

Person for Contacts: ______________________________

Address (if different): ______________________________
____
____

Telephone Number: ______________________________

Company Production/Sales Data

Do you produce light-duty vehicles in Canada? ____________

Annual number vehicles exported? (no. and yr.) ____________
Annual number vehicles imported? (no. and yr.) ____________
Annual number vehicles sold in Canada (No.and Yr)? ____________

Indicate classes of vehicles currently sold, the numbers of engine types (e.g. Diesel, gasoline, carbureted, injected, V-8, 4 cyl., etc) in each, and the number of emission control combinations or system types in each:

	Check	Enter no. of engine and system types			
Sub-compacts?	____	No. Engines	____	No. Emission Systems	____
Compacts?	____	No. Engines	____	No. Emission Systems	____
Intermediates?	____	No. Engines	____	No. Emission Systems	____
Full-sized?	____	No. Engines	____	No. Emission Systems	____
Luxury?	____	No. Engines	____	No. Emission Systems	____
Light duty Trucks?					
Less than 4000 Lbs.	____	No. Engines	____	No. Emission Systems	____
Less than 6000 Lbs.	____	No. Engines	____	No. Emission Systems	____

Do you produce emission control hardware in Canada? ________
If so, what percentage of emission control system value? ________

Do you purchase Canadian-built emission control hardware? ________
If so, what percentage of emission control system valve? ________

If you company builds emission control hardware in Canada or purchases Canadian built emission control hardware, list the items:

PART B

EMISSION CONTROL TECHNOLOGY AND COSTS TO MEET CURRENT STANDARDS

Question B-1

Check the emission control hardware your company uses to meet the currently-applicable emission control standards for gasoline-engined light duty passenger cars and trucks Also, estimate the cost and percent of current production for which the checked hardware would apply. See Part A of the questionnaire for definitions of cost and markup factor.

Gasoline-fueled Engines

Emission Control Hardware	Cost	Markup Factor	Estimated % Production
__ Engine Modifications	____	____	____
__ Air Injection	____	____	____
__ Air Aspiration	____	____	____
__ Air/Fuel Enleanment	____	____	____
__ Exhaust Gas Recirculation	____	____	____
__ High Energy Ignition	____	____	____
__ Electronic Fuel Injection (multiple point injection)	____	____	____
__ Electronic Fuel Injection (throttle body injection)	____	____	____
__ Oxidation Catalyst	____	____	____
__ Feed-back carburetor	____	____	____
__ Three-way catalyst	____	____	____
__ Three-way plus oxidation catalyst	____	____	____
__ Micro-computer Control	____	____	____
__ Stratified Charge	____	____	____
__ Evaporative Emissions Control	____	____	____
__ Other - Identify			
__________	____	____	____
__________	____	____	____

Question B-2

For each currently produced class of gasoline-engined light duty vehicle and emission control hardware combination provide the fuel consumption range (City FTP) and class average fuel consumption (liters/100 km). The emission control hardware combination should be identified by the following abbreviations:

EM - Engine Modifications
FE - Air/Fuel Enleanment
HEI - High Energy Ignition
EFIS - Electronic Fuel Injection (throttle body)
OC - Oxidation Catalyst
TWC - Three-way Catalyst
CC - Micro-computer Control
SC - Stratified Charge
___ - Other ____________

AI - Air Injection
EGR - Exhaust Gas Recirculation
EFIM - Electronic Fuel Injection (multiple point)
FBC - Feed-back Carburetor
TWO - Three-way plus oxidation Catalyst
EVA - Evaporative emissions
___ - Other ____________
___ - Other ____________

Example of emission control combination: EGR,AI, CC, EFIS, OC

		Fuel Consumption	
Class	**Emission Control System**	**Range**	**Average**
Sub-compact	____________	____	____
	____________	____	____
Compact	____________	____	____
	____________	____	____
Intermediate	____________	____	____
	____________	____	____
Full-size	____________	____	____
	____________	____	____
Luxury	____________	____	____
	____________	____	____
Light Truck			
Less than 4000 lbs.	____________	____	____
Less than 6000 lbs.	____________	____	____
Other			
________	____________	____	____
________	____________	____	____

Question B-3

Some of your gasoline-engined light duty passenger car and truck models currently sold in Canada may use emission control hardware with a greater margin of emission control capability than is actually required to meet current emission control standards. The reasons for this might be that your company: produces a common model to meet multi-national emissions standards, or the emission control system enables better fuel consumption or driveability or it is cost-effective to do so. Check the emission control hardware for which the above statement is correct and the reason(s) why.

Check the Reason

Emission Control Hardware	Multi-Nation	Fuel Consump.	Drive-ability	Cost
__ Engine Modifications	___	___	___	___
__ Manifold Air Injection	___	___	___	___
__ Air/Fuel Enleanment	___	___	___	___
__ Exhaust Gas Recirculation	___	___	___	___
__ High Energy Ignition	___	___	___	___
__ Electronic Fuel Injection (multiple point injection)	___	___	___	___
__ Electronic Fuel Injection (throttle body injection)	___	___	___	___
__ Oxidation Catalyst	___	___	___	___
__ Feed-back carburetor	___	___	___	___
__ Three-way catalyst	___	___	___	___
__ Three-way plus oxidation Catalyst	___	___	___	___
__ Micro-computer Control	___	___	___	___
__ Stratified Charge	___	___	___	___
__ Other - Identify				
______________	___	___	___	___
______________	___	___	___	___

If reasons other than above,explain.______________________________________

____

____

Question B-4

Check the emission control hardware your company uses to meet the currently-applicable emission control standards for Diesel-engined light duty passenger cars and trucks Also, estimate the cost and percent of current production for which the checked hardware would apply. See Part A of the questionnaire for the definitions of cost and markup factor.

Diesel Engines

Emission Control Hardware	**Cost**	**Markup Factor**	**Estimated % Production**
__ Engine Modifications	___	___	___
__ Retarded Injection Timing	___	___	___
__ Turbocharger	___	___	___
__ Air/Fuel Ratio Control	___	___	___
__ Decreased Engine Rated Speed	___	___	___
__ Increased Compression Ratio	___	___	___
__ Reduced Displacement	___	___	___
__ High Pressure Injection	___	___	___
__ Intercooling	___	___	___
__ Exhaust Gas Recirculation	___	___	___
__ Low Sac Injectors	___	___	___
__ Optimized Valve Timing	___	___	___
__ Catalyst	___	___	___
__ Particulate Trap	___	___	___
__ Other - Identify			
__________	___	___	___
__________	___	___	___
__________	___	___	___
__________	___	___	___

Question B-5

For each currently produced class of Diesel-engined light duty vehicle and emission control hardware combination provide the fuel consumption range (City FTP) and class average fuel consumption (liters/100 km). The emission control hardware combination should be identified by the following abbreviations:

EM - Engine Modifications
TC - Turbocharger
AFC - Air/Fuel Ratio Control
IC - Increased Compression Ratio
OC - Oxidation Catalyst
HPI - High Pressure Injection
LSI - Low Sac Injectors
PT - Particulate Trap
___ - Other ______________

RT - Retarded Injection Timing
EGR - Exhaust Gas Recirculation
DS - Decreased Engine Rated Speed
RD - Reduced Displacement
ITC - Intercooling
OVT - Optimized Valve Timing
___ - Other ______________
___ - Other ______________

Example of emission control combination: EM,LSI,RT

Class	Emission Control System	Fuel Consumption	
		Range	Average
Sub-compact	______________	____	____
	______________	____	____
Compact	______________	____	____
	______________	____	____
Intermediate	______________	____	____
	______________	____	____
Full-size	______________	____	____
	______________	____	____
Luxury	______________	____	____
	______________	____	____
Light Truck			
Less than 4000 lbs.	______________	____	____
Less than 6000 lbs	______________	____	____
Other			
__________	______________	____	____
__________	______________	____	____

Question B-6

Some of your Diesel-engined light duty passenger car and truck models currently sold in Canada may use emission control hardware with a greater margin of emission control capability than is actually required to meet current emission control standards. The reasons for this might be that your company: produces a common model to meet multi-national emissions standards, or the emission control system enables better fuel consumption or driveability or it is cost-effective to do so. Check the emission control hardware for which the above statement is correct and the reason(s) why.

Check the Reason

Emission Control Hardware	**Muti-Nation**	**Fuel Consump.**	**Drive-ability**	**Cost**
__ Engine Modifications	___	___	___	___
__ Retarded Injection Timing	___	___	___	___
__ Turbocharger	___	___	___	___
__ Exhaust Gas Recirculation	___	___	___	___
__ Air/Fuel Ratio Control	___	___	___	___
__ Decreased Engine Rated Speed	___	___	___	___
__ Increased Compression Ratio	___	___	___	___
__ Reduced Displacement	___	___	___	___
__ High Pressure Injection	___	___	___	___
__ Intercooling	___	___	___	___
__ Low Sac Injectors	___	___	___	___
__ Optimized Valve Timing	___	___	___	___
__ Catalyst	___	___	___	___
__ Particulate Trap	___	___	___	___
__ Other - Identify				
___________	___	___	___	___
___________	___	___	___	___
___________	___	___	___	___

If reasons other than above, explain.______________________________

____

____

PART C

EMISSION CONTROL TECHNOLOGY AND COSTS TO MEET PROPOSED STANDARDS

Question C-1

For the proposed emission standard of .25 HC, 4.35 CO, and .62 NO_x, (1.05 HC, 11.16 CO, 1.92 NO_x for light duty trucks) check the emission control hardware your company would plan or consider using for compliance in model year 1986 of your gasoline-engined light duty passenger cars and trucks Also, estimate the costs of the hardware. See Part A of the questionnaire for definitions of cost and markup factor.

Gasoline-engined Passenger Cars

Emission Control Hardware	Cost	Markup Factor
__ Engine Modifications	___	___
__ Manifold Air Injection	___	___
__ Air/Fuel Enleanment	___	___
__ Exhaust Gas Recirculation	___	___
__ High Energy Ignition	___	___
__ Electronic Fuel Injection (multiple point injection)	___	___
__ Electronic Fuel Injection (single point injection)	___	___
__ Oxidation Catalyst	___	___
__ Feed-back carburetor	___	___
__ Three-way catalyst	___	___
__ Three-way plus oxidation Catalyst	___	___
__ Micro-computer Control	___	___
__ Stratified Charge	___	___
__ Other - Identify		
____________	___	___

Also, estimate the cost of a system to meet 2 grams SHED evaporative standard.

Evaporative System	___	___

Question C-1 (continued)

Complete same question for light duty gasoline-engined trucks. Note that proposed emission standard for light duty trucks is 1.05 HC, 11.16 CO, and 1.92 NO_x.

Gasoline-engined Light Duty Trucks

Emission Control Hardware	**Cost**	**Markup Factor**
__ Engine Modifications	___	___
__ Manifold Air Injection	___	___
__ Air/Fuel Enleanment	___	___
__ Exhaust Gas Recirculation	___	___
__ High Energy Ignition	___	___
__ Electronic Fuel Injection (multiple point injection)	___	___
__ Electronic Fuel Injection (throttle body injection)	___	___
__ Oxidation Catalyst	___	___
__ Feed-back carburetor	___	___
__ Three-way catalyst	___	___
__ Three-way plus oxidation Catalyst	___	___
__ Micro-computer Control	___	___
__ Stratified Charge	___	___
__ Other - Identify		
______________	___	___

Also, estimate the cost of a system to meet 2 grams SHED evaporative standard.

Evaporative System	___	___

Question C-2

Provide the combinations of emission control hardware identified in question C-1 that you would consider using for each class of gasoline-fueled light duty passenger car and truck that you expect to produce in 1986. Also, provide the aggregate cost for the emission control hardware combination and any anticipated impact on fuel consumption, expressed as percent increase (decrease) in fuel consumption. The emission control hardware combination should be identified by the following abbreviations:

EM - Engine Modifications
FE - Air/Fuel Enleanment
HEI - High Energy Ignition
EFIS - Electronic Fuel Injection (Throttle Body Injection)
OC - Oxidation Catalyst
TWC - Three-way Catalyst
CC - Micro-computer Control
SC - Stratified Charge
___ - Other ________________

AI - Air Injection
EGR - Exhaust Gas Recirculation
EFIM - Electronic Fuel Injection (Multiple point)
FBC - Feed-back Carburetor
TWO - Three-way plus oxidation Catalyst
EVA - Evaporative emissions
___ - Other ________________
___ - Other ________________

Example of emission control combination: EGR,AI, CC, EFIS, OC

Class	**Emission Control System**	**Cost**	**% Fuel Consumption Impact**
Sub-compact	____________________	_____	_____
	____________________	_____	_____
Compact	____________________	_____	_____
	____________________	_____	_____
Intermediate	____________________	_____	_____
	____________________	_____	_____
Full-size	____________________	_____	_____
	____________________	_____	_____
Luxury	____________________	_____	_____
	____________________	_____	_____
Light Truck			
Less than 4000 lbs.	____________________	_____	_____
Less than 6000 lbs.	____________________	_____	_____
Other			
__________	____________________	_____	_____

Question C-3

Do you anticipate any impacts on vehicle driveability, durability, or maintenance requirements as a result of installing the emission control hardware requirements identified in Question C-2? Explain.

Question C-4

The proposed standards are targeted for a compliance date of 1986. Is there adequate lead-time for your company to comply? If not, provide the lead-time required for your company. Explain the reasons, e.g., administrative, engineering design, retooling, etc.

Question C-5

What percentage of the emission control hardware combination identified in question C-2 would your company manufacture in Canada or purchase from suppliers who would manufacture the hardware in Canada?

Emission Control System Combination	**Percentage**

Question C-6

For the proposed emission standard of .25 HC, 4.35 CO, and .62 NO_x,(1.05 HC, 1.16 CO, 1.92 NO_x for trucks), check the emission control hardware your company would plan or consider using for compliance in 1986 of your Diesel-engined light duty passenger cars and estimate the costs of the hardware. Repeat the question for a less stringent standard of .93 NO_x by indicating the NO_x standard to which the hardware selection would apply in the last column.

Diesel-engined Passenger Cars

Emission Control Hardware	Cost	Markup Factor	NO_x Standard
__ Engine Modifications	____	____	____
__ Retarded Injection Timing	____	____	____
__ Turbocharger	____	____	____
__ Air/Fuel Ratio Control	____	____	____
__ Decreased Engine Rated Speed	____	____	____
__ Increased Compression Ratio	____	____	____
__ Reduced Displacement	____	____	____
__ High Pressure Injection	____	____	____
__ Intercooling	____	____	____
__ Exhaust Gas Recirculation	____	____	____
__ Low Sac Injectors	____	____	____
__ Optimized Valve Timing	____	____	____
__ Catalyst	____	____	____
__ Particulate Trap	____	____	____
__ Other			
____________	____	____	____
____________	____	____	____
____________	____	____	____

Question C-6 (Continued)

Complete the same question for Diesel-engined light duty trucks. Note that the proposed emission standard is 1.05 HC, 11.16 CO, 1.92 NO_x for light duty trucks.

Diesel-engined Light Duty Trucks

Emission Control Hardware	**Cost**	**Markup Factor**	**NO_x Standard**
__ Engine Modifications	___	___	___
__ Retarded Injection Timing	___	___	___
__ Turbocharger	___	___	___
__ Air/Fuel Ratio Control	___	___	___
__ Decreased Engine Rated Speed	___	___	___
__ Increased Compression Ratio	___	___	___
__ Reduced Displacement	___	___	___
__ High Pressure Injection	___	___	___
__ Intercooling	___	___	___
__ Exhaust Gas Recirculation	___	___	___
__ Low Sac Injectors	___	___	___
__ Optimized Valve Timing	___	___	___
__ Catalyst	___	___	___
__ Particulate Trap	___	___	___
__ Other			
___________	___	___	___
___________	___	___	___
___________	___	___	___

Question C-7

Provide the combinations of emission control hardware identified in question C-6 that you would consider using for each class of Diesel-engined light duty vehicle that you expect to produce in 1986. Indicate whether it is control combination for .62 or .93 NO_x. Also, provide the aggregate cost for the emission control hardware combination and any anticipated impact on fuel consumption, expressed as percent increase (decrease) in fuel consumption. The emission control hardware combination should be identified by the following abbreviations:

EM - Engine Modifications
TC - Turbocharger
AFC - Air/Fuel Ratio Control
IC - Increased Compression Ratio
OC - Oxidation Catalyst
HPI - High Pressure Injection
LSI - Low Sac Injectors
PT - Particulate Trap
___ - Other ____________

RT - Retarded Injection Timing
EGR - Exhaust Gas Recirculation
DS - Decreased Engine Rated Speed
RD - Reduced Displacement
ITC - Intercooling
OVT - Optimized Valve Timing
___ - Other ____________
___ - Other ____________

Example of emission control combination: EM,LSI,RT

Class	**Emission Control System Combination**	**Total Cost**	**% Impact Fuel Consumption**
Sub-compact	________	______	______
	________	______	______
Compact	________	______	______
	________	______	______
Intermediate	________	______	______
	________	______	______
Full-size	________	______	______
	________	______	______
Luxury	________	______	______
	________	______	______
Light Truck Less than 4000 lbs.	________	______	______
Less than 6000 lbs.	________	______	______
Other			
______	________	______	______

Question C-8

Do you anticipate any impacts on vehicle driveability, durability, or maintenance requirements as a result of installing the emission control hardware requirements identified in Question C-7? Explain.

Question C-9

The proposed standards are targeted for a compliance date of 1986. Is there adequate lead-time for your company to comply? If not, provide the lead-time required for your company. Explain the reasons, e.g, administrative, engineering design, retooling, etc.

Question C-10

What percentage of the emission control hardware combination would your company manufacture in Canada or purchase from suppliers who would manufacture the hardware in Canada?

Emission Control System Combination	Percentage

Question C-11

Identify the additional, if any, emission control hardware that would be required if your Diesel-engined vehicles had to meet a particulate standard of 0.37 gm/km in addition to the proposed gaseous emission standards.

____

____

____

____

____

Question C-12

If additional emission control hardware was identified in question C-11, provide the impacts, if any, upon emission control hardware cost, fuel consumption, driveability, durability, and maintenance requirements. Also, discuss impact on lead-time.

Element	Impact
Emission Control Hardware Cost	_____(dollars)
Fuel Consumption	_____(percent increase)

Driveability Explain ______________________________

____

____

Durability Explain ______________________________

____

____

Maintenance Explain ______________________________

____

____

Lead-time Explain ______________________________

____

____

PART D

EMISSION CONTROL TECHNOLOGY AND COSTS TO MEET INTERMEDIATE STANDARDS

Question D-1

In addition to the current and proposed emission standards, an intermediate standard of .93 HC, 9.3 CO, and 1.24 NO_x was selected for study, based on the premise that this standard would not require catalyst use on greater than 25% of vehicle production. Check the emission control hardware your company would plan or consider using for compliance of your gasoline-engined light duty passenger vehicles to this intermediate standard. Also, estimate the costs of the emission control hardware.

Gasoline-fueled Engines

Emission Control Hardware	Cost	Markup Factor
__ Engine Modifications	___	___
__ Manifold Air Injection	___	___
__ Air/Fuel Enleanment	___	___
__ Exhaust Gas Recirculation	___	___
__ High Energy Ignition	___	___
__ Electronic Fuel Injection (multiple point injection)	___	___
__ Electronic Fuel Injection (throttle body injection)	___	___
__ Oxidation Catalyst	___	___
__ Feed-back carburetor	___	___
__ Three-way catalyst	___	___
__ Three-way plus oxidation catalyst	___	___
__ Micro-computer Control	___	___
__ Stratified Charge	___	___
__ Other - Identify		
___________	___	___
___________	___	___

Question D-1 (Continued)

If you do not require catalyst use on greater than 25% of your passenger car production in your previous answer, at what emission standard would you require use on greater than 25% of your production?

Identify emission standard ______________________________

At what emission standard would you not be able to offer a lead tolerant engine?

Identify emission standard ______________________________

Identify class(es) of vehicles affected?

Sub-compact __________
Compact __________
Intermediate __________
Full-size __________
Luxury __________
Light truck
  Less than 4000 lbs __________
  Less than 6000 lbs __________

At what emission standard would you require use of three-way catalysts?

Identify emission standard ______________________________

Identify class(es) of vehicles affected?

Sub-compact __________
Compact __________
Intermediate __________
Full-size __________
Luxury __________
Light truck __________
  Less than 4000 lbs __________
  Less than 6000 lbs __________

Question D-2

Provide the combinations of emission control hardware identified in question D-1 that you would consider using for each class of gasoline-engined passenger vehicle that you expect to produce in 1986. Also, provide the aggregate cost for the emission control hardware combination and any anticipated impact on fuel consumption, expressed as percent increase (decrease) in fuel consumption. The emission control hardware combination should be identified by the following abbreviations:

EM - Engine Modifications
FE - Air/Fuel Enleanment
HEI - High Energy Ignition
EFIS - Electronic Fuel Injection (throttle body)
OC - Oxidation Catalyst
TWC - Three-way Catalyst
CC - Micro-computer Control
SC - Stratified Charge
___ - Other ________

AI - Air Injection
EGR - Exhaust Gas Recirculation
EFIM - Electronic Fuel Injection (Multiple point)
FBC - Feed-back Carburetor
TWO - Three-way plus oxidation Catalyst
EVA - Evaporative emissions
___ - Other ________
___ - Other ________

Example of emission control combination: EGR,AI, CC, EFIS, OC

Class	Emission Control System	Cost	% Fuel Consumption Impact
Sub-compact			
Compact			
Intermediate			
Full-size			
Luxury			
Other			

Question D-3

Do you anticipate any impacts on vehicle driveability durability, or maintenance requirements as a result of installing the emission control hardware requirements identified in Question D-2? Explain.

Question D-4

The intermediate standards are targeted for a compliance date of 1986. Is there adequate lead-time for your company to comply? If not, provide the lead-time required for your company. Explain the reasons, e.g. administrative, engineering design, retooling, etc.

Question D-5

What percentage of the emission control hardware combination would your company manufacture in Canada or purchase from suppliers who would manufacture the hardware in Canada?

Emission Control System Combination	Percentage

Question D-6

For the intermediate emission standard of .93 HC, 9.3 CO, and 1.24 NO_x, check the emission control hardware your company would plan or consider using for compliance of your Diesel-engined passenger vehicles. Also, estimate the costs of the hardware.

Diesel Engines

Emission Control Hardware	Cost	Markup Factor
___ Engine Modifications		
__ Retarded Injection Timing	___	___
__ Turbocharger	___	___
__ Air/Fuel Ratio Control	___	___
__ Decreased Engine Rated Speed	___	___
__ Increased Compression Ratio	___	___
__ Reduced Displacement	___	___
__ High Pressure Injection	___	___
__ Intercooling	___	___
__ Exhaust Gas Recirculation	___	___
__ Low Sac Injectors	___	___
__ Optimized Valve Timing	___	___
__ Catalyst	___	___
__ Particulate Trap	___	___
__ Other		
___________	___	___
___________	___	___
___________	___	___

Question D-7

Provide the combinations of emission control hardware identified in question D-6 that you would consider using for each class of Diesel-engined passenger vehicle that you expect to produce in 1986. Also, provide the aggregate cost for the emission control hardware combination and any anticipated impact on fuel consumption, expressed as percent increase (decrease) in fuel consumption. The emission control hardware combination should be identified by the following abbreviations:

EM - Engine Modifications
TC - Turbocharger
AFC - Air/Fuel Ratio Control
IC - Increased Compression Ratio
OC - Oxidation Catalyst
HPI - High Pressure Injection
LSI - Low Sac Injectors
PT - Particulate Trap
___ - Other ____________

RT - Retarded Injection Timing
EGR - Exhaust Gas Recirculation
DS - Decreased Engine Rated Speed
RD - Reduced Displacement
ITC - Intercooling
OVT - Optimized Valve Timing
___ - Other ____________
___ - Other ____________

Example of emission control combination: EM,LSI,RT

Class	**Emission Control System Combination**	**Total Cost**	**% Impact Fuel Consumption**
Sub-compact			
Compact			
Intermediate			
Full-size			
Luxury			
Other			

Question D-8

Do you anticipate any impacts on vehicle driveability, durability, or maintenance requirements as a result of installing the emission control hardware requirements identified in Question D-7? Explain.

Question D-9

The intermediate standards are targeted for a compliance date of 1986. Is there adequate lead-time for your company to comply? If not, provide the lead-time required for your company. Explain the reasons, e.g. administrative, engineering design, retooling, etc.

Question D-10

What percentage of the emission control hardware combination would your company manufacture in Canada or purchase from suppliers who would manufacture the hardware in Canada?

Emission Control System Combination	Percentage

Question D-11

Identify the additional, if any, emission control hardware that would be required if your Diesel-engined vehicles had to meet a particulate standard of 0.37 gm/km in addition to the intermediate exhaust emission standards.

____

____

____

____

____

Question D-12

If additional emission control hardware was identified in question D-11, provide the impacts, if any, upon emission control hardware cost, fuel consumption, driveability, durability, and maintenance requirements. Also, discuss impact on lead-time.

Element	**Impact**
Emission Control Hardware Cost?	_____(dollars)
Fuel Consumption?	_____(percent increase)

Driveability Explain ______________________________

____

____

Durability Explain ______________________________

____

____

Maintenance Explain ______________________________

____

____

Lead-time Explain ______________________________

____

____

PART E

COLD WEATHER PERFORMANCE OF EMISSION CONTROL TECHNOLOGY

The compliance test procedure (FTP) for measuring emissions is run in the temperature range of 20 degrees C to 30 degrees C. Generally it is found that exhaust emissions from vehicles as measured on the FTP increase in a non-linear fashion with decreasing ambient temperatures. Consequently, a proportional rollback in emission standards may not produce a proportional roll-back in actual vehicle emissions because of the colder climate in Canada.

If your company has performed cold weather testing of vehicles it is requested that you enclose data, reports, and other relevent information with the completed questionnaire.

Question E-1

It is believed that a major portion of increased emissions (as measured by the FTP) during cold weather testing occurs during cold start or bag one of the FTP. What emission control hardware would your company utilize if it were required to reduce cold start emissions?

Describe for each class of vehicle:
____
____
____
____
____
____
____
____
____
____
____
____
____
____
____
____

PART F

FUEL MODIFICATION EFFECTS ON EXHAUST EMISSIONS

The study includes examination of the effects of long-range changes in fuel composition on exhaust emissions. These changes may be attributeable to the use of synthetic fuels derived from coal, biomass, tar sands, and oil shale or the use of fuel additives, such as MMT. Any information your company could provide would be appreciated.